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RESEARCH MEMORANDUM

PERFORMANCE OF DOUBLE-SHROUD EJECTOR CONFIGURATION

WITH PRIMARY PRESSURE RATIOS FROM 1.0 TO 10

By Donald P. Hollister and William K. Greathouse

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Cleveland, Ohio

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PERFORMANCE OF DOUBLE-SHROUD EJECTOR CONFIGURATION WITH

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SUMMARY

A brief investigation was made to determine the performance characteristics of a double-shroud cooling-air ejector configuration. Two convergent primary nozzles were used to simulate a specific manufacturer's iris-type variable-area nozzle in the open and closed positions. The investigation comprised four phases: (1) obtaining performance with no secondary or tertiary air flow (cooling-air passages blocked), (2) determining the tendency for backflow to occur in either cooling-air passage, (3) determining the sensitivity of flow in one passage to that in the other, and (4) obtaining pumping and thrust characteristics with secondary and tertiary air flow.

The experimental results showed that the performance with the cooling-air passages blocked was typical of that for single ejectors having diameter and spacing ratios similar to those used in this investigation. There was a tendency for backflow to occur, but the magnitude of such flow was relatively small. The weight flow of each ejector was shown to be essentially independent of the other, and the closed primary-nozzle configuration was found to be generally capable of pumping more cooling-air than the open primary-nozzle configuration. Gains in gross thrust were observed for both configurations, with losses occurring only at low secondary and tertiary pressure ratios.

INTRODUCTION

The use of afterburners for thrust augmentation, and particularly the advent of high-temperature afterburners, increases the cooling-air requirements of turbojet engines. Single-shroud ejectors are now being used for supplying the cooling air. In some aircraft installations, however, it is necessary to provide an additional quantity of air for cooling the aircraft structure; the use of double-shroud ejectors for meeting this requirement is now under consideration.

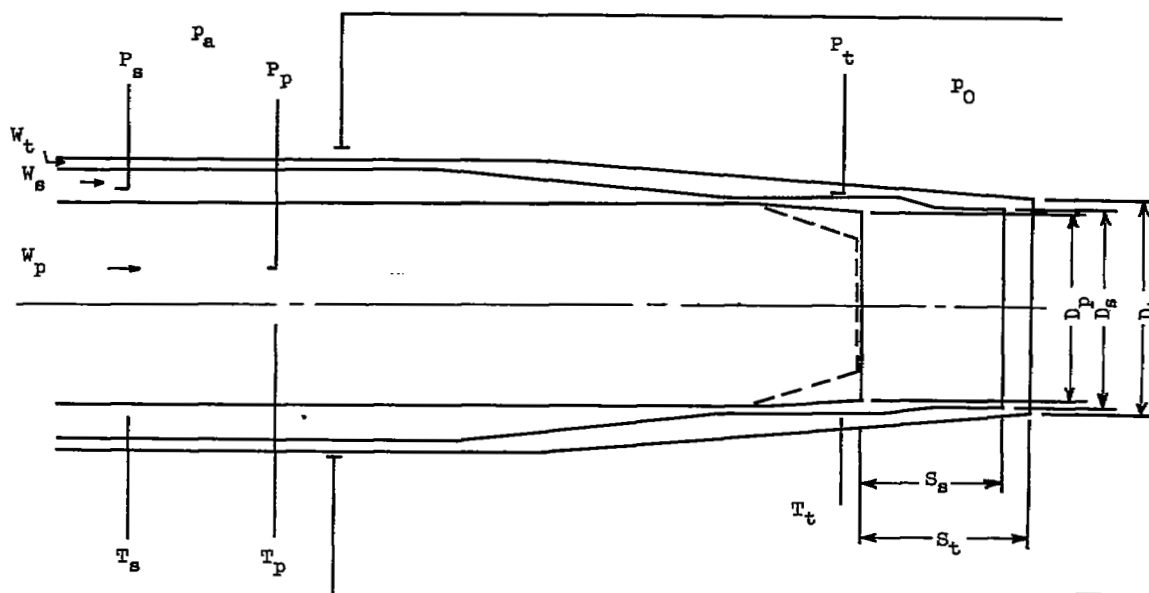
The single-shroud ejector has been the subject of several experimental investigations (references 1 to 7), but the available information on double-shroud ejectors is very limited. In reference 8, the operating mechanism of double-shroud ejectors is discussed, the performance of several configurations is presented, and it is shown that an ejector of this type can be designed to operate satisfactorily.

The double-shroud ejector configurations used in this investigation incorporated two convergent primary nozzles to simulate a specific manufacturer's iris-type variable-area nozzle in the closed and open positions. Although this investigation was limited to only two configurations, a wider range of pressure ratios and operating conditions was covered than in the investigation reported in reference 8, which primarily presented the pumping and thrust characteristics of each configuration for only four primary pressure ratios. In the present investigation, the thrust and pumping characteristics of both configurations were investigated for eight constant primary pressure ratios from 1.10 to 9.5. Additional tests were conducted to determine (1) ejector performance with no cooling-air flow, (2) the tendency for backflow to occur from the primary jet into either the secondary or the tertiary system, and (3) whether or not the flow through each cooling-air system was independent of the flow through the other. This investigation was conducted using dry unheated air at a temperature of 80° F.

SYMBOLS AND NOMENCLATURE

The following symbols and nomenclature used in this report are defined in the accompanying schematic sketch of a double-shroud ejector. It should be noted that primary refers to the engine nozzle, secondary denotes the inner annulus, and tertiary denotes the outer annulus:

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D_p exit diameter of primary nozzle, in.

D_s exit diameter of inner shroud, in.

D_t exit diameter of outer shroud, in.

D_s/D_p inner-shroud diameter ratio

D_t/D_p outer-shroud diameter ratio

F_{ej} gross thrust of ejector, lb

F_j gross thrust of primary nozzle with shrouds removed, lb

F_{ej}/F_j gross thrust ratio

P_p	primary-stream total pressure, in. mercury abs.
P_s	secondary-stream total pressure, in. mercury abs.
P_t	tertiary-stream total pressure, in. mercury abs.
P_p/P_0	primary pressure ratio
P_s/P_0	secondary pressure ratio
P_t/P_0	tertiary pressure ratio
P_a	atmospheric pressure, in. mercury abs.
P_0	ambient exhaust pressure, in. mercury abs.
S_s	distance from primary-nozzle exit to exit of inner shroud, inner-shroud spacing, in.
S_t	distance from primary-nozzle exit to exit of outer shroud, outer-shroud spacing, in.
S_s/D_p	inner-shroud spacing ratio
S_t/D_p	outer-shroud spacing ratio
T_p	primary-stream total temperature, $^{\circ}\text{R}$
T_s	secondary-stream total temperature, $^{\circ}\text{R}$
T_t	tertiary-stream total temperature, $^{\circ}\text{R}$
W_p	primary weight flow, lb/sec
W_s	secondary weight flow, lb/sec
W_t	tertiary weight flow, lb/sec
W_s/W_p	secondary weight-flow ratio
W_t/W_p	tertiary weight-flow ratio

APPARATUS

Ejector Research Facility

2765 The ejector-research facility shown in figure 1 consists of two concentric ducts simulating an engine tail pipe and a cooling-air passage. For this investigation, a third concentric duct was added to provide a cooling-air passage for the outer shroud. Air was supplied from the laboratory air-supply system to these ducts, as shown, and was passed through the primary nozzle and the cooling-air passages into the exhaust chamber. The air was supplied at a pressure of 40 pounds per square inch gage, a temperature of approximately 80° F, and a dew point of -20° F. The exhaust chamber was connected to the laboratory exhaust system so that the ejector exit pressure could be varied from atmospheric to about 2 pounds per square inch absolute.

The primary, secondary, and tertiary air flows were measured by means of standard A.S.M.E. sharp-edge orifices. The total pressures and temperatures were measured with total-pressure tubes and single, bare-wire, iron-constantan thermocouples, respectively. The primary measuring station, located 20 inches upstream of the primary-nozzle exit, consisted of two total-pressure tubes, two wall static taps, and one thermocouple. The total-pressure tubes and the thermocouple projected about one-third of the duct diameter into the stream, because surveys had shown that measurements at this location gave the average of the total-pressure profile. The secondary instrumentation, consisting of two total pressure tubes and one thermocouple, was located at a station about $27\frac{1}{2}$ inches upstream of the primary-nozzle exit. This instrumentation was duplicated for the tertiary stream at a station about $1\frac{1}{8}$ inches upstream of the primary-nozzle exit. The ejector exit pressure was measured in the exit plane of the outer shroud by means of two static-pressure tubes attached to the outside wall of the outer shroud.

The lower portion of the facility is connected to the laboratory-air supply system by means of flexible bellows and is pivoted to a steel frame in order that the axial force may be freely transmitted to a null-type balanced-pressure diaphragm, thrust-measuring cell. The output pressure of this cell is directly proportional to the applied force and, hence, is a direct measure of the resultant force acting on the ejector in an axial direction. In order that the force on the thrust cell would always be in one direction, an axial preload force, consisting of a counterweight connected to the rig by large pulleys and steel tapes, was applied to the thrust cell.

Ejector Models

In this investigation two conical nozzles having areas equivalent to a specific manufacturer's iris-type variable-area nozzle in the open and closed positions were used. The relative location of the shrouds with respect to the two primary nozzles is shown in figure 2. The open and closed primary nozzles had exit diameters of 4.79 and 3.49 inches, respectively, and the corresponding half-cone angles were $20^{\circ}57'$ and $20^{\circ}35'$. The inside diameter of the approach pipe to the primary nozzles was 5 inches. The inner shroud was essentially cylindrical and had an exit diameter of 5.65 inches. The conical outer shroud had an exit diameter of 6.30 inches and a half-cone angle of $7^{\circ}18'$. The spacing and diameter ratios for both configurations are shown in the table in figure 2.

PROCEDURE

Each of the two primary nozzles was calibrated to determine the flow coefficients and the primary nozzle thrust over a range of pressure ratios from 1.0 to 10. The various primary pressure ratios were obtained by throttling the inlet air and by reducing the ambient pressure in the exhaust chamber. With the shrouds in place, the investigation of each complete double-shroud ejector configuration consisted of four phases. The first phase was an investigation of the performance over a range of primary pressure ratios from 1.0 to 10 with the shroud-inlet passages blocked (zero secondary and tertiary air flow). The second phase consisted in determining the tendency for backflow to occur in either of the two cooling-air passages and the magnitude of such flow. In order to accomplish this, the duct controlling the total air flow to the two cooling-air passages was blocked while the valves interconnecting the secondary and tertiary systems were open so as to allow air to circulate through the two interconnected systems.

The third phase was an investigation of the interaction and consequent sensitivity of each cooling-air system to the other. This phase was conducted at a constant primary pressure ratio of about 3.0; while the tertiary weight flow ratio, and hence the tertiary pressure ratio, was varied over a range of values, and the secondary weight flow ratio was so varied as to maintain a constant secondary pressure ratio of 1.30. In this way the effect of tertiary flow on the secondary weight-flow ratio was determined. The effect of secondary flow on the tertiary weight-flow ratio was determined in a similar manner; that is, by varying the secondary weight-flow ratio while a constant tertiary pressure ratio of 1.30 was being maintained.

The final phase was that of determining the pumping and thrust characteristics for a range of constant primary pressure ratios from 1.10 to 9.5. This phase was conducted with the total pressures in the two cooling passages approximately equal, so as to simulate a common inlet and plenum chamber for the two cooling-air passages. Although ejector performance was determined with 80° F primary, secondary, and tertiary air, the weight flow ratios presented herein are multiplied by $\sqrt{T_s/T_p}$ and $\sqrt{T_t/T_p}$ as a reminder that the application of these data to hot jet installations requires a temperature correction.

The axial force transmitted to the thrust cell was composed of the ejector thrust force, the pressure-area force imposed on the system by the difference between atmospheric pressure and the ejector exit pressure in the exhaust chamber, and the axial preload force. The pressure-area force was determined from a calibration over the range of ejector-exit pressures used in the investigation. The ejector thrust was obtained by subtracting the force acting on the thrust cell from the sum of the preload and the pressure-area forces. In order that the thrust data be consistent and accurate, the pressure-area force-calibration curve was checked daily throughout the investigation.

RESULTS AND DISCUSSION

Zero Secondary and Tertiary Flow

Performance. - The performance of the closed and the open primary-nozzle configurations with zero secondary and tertiary air flow is shown in figures 3(a) and 3(b) and in table I. The effect of primary pressure ratio on secondary pressure ratio is typical of single-shroud cylindrical ejectors having diameter and spacing ratios similar to those used in this investigation. The effect of primary pressure ratio on tertiary pressure ratio is typical of that of single-shroud conical ejectors having very small spacing ratios; such would be the case if the inner shroud were considered the primary nozzle and the spacing were the distance from the exit of the inner shroud to the exit of the outer shroud.

It should be noted that the curve of secondary pressure ratio in figure 3(a) exhibits a marked amount of hysteresis and the tertiary pressure ratio curve shows a slight amount of hysteresis in the primary pressure ratio range from 3.5 to 5.0 as indicated by the arrows on the curves. This phenomenon has previously been encountered with cylindrical ejectors having large diameter ratios and small spacing ratios, as shown in reference 1, but has not been observed for small diameter ratios. Hysteresis occurs because the primary jet remains attached to the shroud wall until the primary pressure ratio is decreased to a value less than that at which attachment first occurred as the primary pressure ratio

was being increased. The jet finally becomes detached at this lower primary pressure ratio, and the shroud pressures assume their normal values. A further discussion of this hysteresis may be found in reference 1.

Thrust characteristics. - The effect of primary pressure ratio on gross thrust ratio for zero secondary and tertiary air flow is presented in figure 4(a) for the closed primary-nozzle configuration and in figure 4(b) for the open primary-nozzle configuration. Gross thrust ratio is defined as the ratio of ejector gross thrust F_{ej} to the primary nozzle (ejector shrouds removed) gross thrust F_j at the same primary pressure ratio. Ejector gross thrust F_{ej} , then, includes the combined thrust produced by the mass flow through the cooling-air passages, and the primary-nozzle gross thrust F_j includes only the thrust produced by the mass flow through the primary nozzle.

The thrust characteristics with the closed-nozzle configuration (fig. 4(a)) exhibit hysteresis similar to that for the secondary pressure ratio (fig. 3(a)), and indicate that a loss in gross thrust of as much as 33 percent of primary-nozzle gross thrust is possible with this configuration when the cooling-air flow is zero. Hysteresis did not occur for the open primary-nozzle configuration with zero cooling-air flow (fig. 4(b)); the greatest loss in gross thrust occurred at a primary pressure ratio of 2.0 and amounted to about 17 percent of the primary-nozzle gross thrust.

A comparison of figures 4(b) and 3(b) shows that the minimum gross thrust ratio occurred at the primary pressure ratio for which the secondary pressure ratio was a minimum, and that a slight dip occurred in the gross-thrust-ratio curve at the primary pressure ratio for which the tertiary pressure ratio was a minimum. This phenomenon may be attributed to shock losses accompanying the overexpansion of the primary jet. A more complete discussion of the effects of overexpansion and shock losses on ejector thrust may be found in reference 2.

A further comparison of figures 4(a) and 4(b) indicates that with zero secondary and tertiary flow, the gross thrust was higher with the open primary-nozzle configuration (small diameter ratio). This relation is consistent with the trends indicated by the data of reference 2.

Effect of Primary Pressure Ratio on Backflow

In order for backflow to occur in one of the two cooling-air passages, the pressure in one passage must be higher than the pressure in the other. An inspection of figures 3(a) and 3(b) indicates the regions of primary

pressure ratio in which backflow will occur. That is, for the regions in which the secondary pressure ratio curve lies below the tertiary pressure ratio curve, (secondary pressure ratio is less than tertiary pressure ratio in figs. 3(a) and 3(b)), the circulation of air is in the normal direction through the secondary passage and is reversed through the tertiary system. For the opposite conditions of secondary and tertiary pressure ratio, the circulation is reversed.

The effect of primary pressure ratio on backflow is shown in figures 5(a) and 5(b) and in table II for the closed and the open primary nozzles. The magnitude of the backflow, although measurable, was very small; less than 0.2 percent of primary air flow through the closed-nozzle configuration, and slightly exceeding 0.4 percent of primary air flow for the open-nozzle configuration. This test simulated a common inlet plenum chamber for the two cooling-air passages with no external source of air; the positive portion of each curve therefore indicates circulation in the normal direction through the secondary passage and in a reverse direction through the tertiary system. The negative portion of the curve indicates circulation in the opposite direction, with backflow occurring through the secondary system and flow in the normal direction existing in the tertiary passage. The direction of the circulation flow for each configuration reverses (magnitude of backflow becomes zero) at approximately the same primary pressure ratios at which the value of primary and secondary pressure ratio become equal (figs. 3(a) and 3(b)). It should be noted that the data of figure 5(a) were obtained in the direction of increasing primary pressure ratio, and thus any effect of hysteresis on backflow is not included.

Interaction of Secondary and Tertiary Systems

Investigation of the interaction between the secondary and tertiary flow systems indicated that there was little interaction between the two systems. The weight flow through each shroud was insensitive to changes through the other, as shown in table III and in figures 6 to 9 for the closed and the open primary nozzles. For a primary pressure ratio of about 3.0 and a secondary pressure ratio of about 1.3, with the primary nozzle in the closed position, the secondary weight-flow ratio was essentially independent of the tertiary weight-flow ratio as the tertiary weight-flow-ratio increased from 0.02 to 0.15 (fig. 6). Likewise, while varying the secondary weight-flow ratio with the primary nozzle closed, the tertiary weight-flow ratio was essentially constant for a constant tertiary pressure ratio of about 1.3 (fig. 7). Similar results were obtained for the open primary-nozzle configuration (figs. 8 and 9). Although this effect was investigated only at a primary pressure ratio of about 3.0, it is believed that these characteristics are representative of those which would be obtained at other primary pressure ratios.

Ejector Performance

Pumping characteristics. - The pumping characteristics of the double-shroud ejector configuration with the closed primary nozzle are presented in figure 10 for several primary pressure ratios from 1.10 to 9.5, and are tabulated in table IV. As mentioned previously, the total pressures in the two cooling passages were maintained approximately equal for this phase of the investigation. The effect of secondary pressure ratio on secondary weight-flow ratio is shown in figure 10(a), and the corresponding tertiary-system pumping characteristics are shown in figure 10(b). A comparison of the two figures discloses that the pumping ability of the secondary and the tertiary systems are nearly identical. It is evident from these data that at low primary pressure ratios secondary and tertiary weight-flow ratios were extremely sensitive to variations in secondary and tertiary pressure ratios. As the primary pressure ratio was increased this sensitivity of secondary and tertiary flow became less pronounced.

The secondary and the tertiary weight-flow ratios with the open primary nozzle are shown in figures 11(a) and 11(b), respectively, and in table IV. A comparison of these figures reveals that the secondary outperforms the tertiary system at the lower primary pressure ratios over the entire range of secondary and tertiary pressure ratio, and at primary pressure ratios of 3.0 and 4.0 at the lower secondary and tertiary pressure ratios. For the three highest primary pressure ratios investigated (6.0, 8.0, and 9.5), the tertiary system pumps a far greater amount of air than the secondary. Again, the sensitivity of the weight-flow ratios to changes in secondary and tertiary pressure ratio decreased greatly with increasing primary pressure ratio.

A comparison of figures 10 and 11 shows that, for a given primary pressure ratio, the weight-flow ratios for the open primary-nozzle configuration are, in general, considerably lower than for the closed-primary configuration. This comparison also discloses, as pointed out in reference 8, that for the closed primary-nozzle configuration (large diameter ratio), the secondary and tertiary weight-flow ratios were more sensitive to changes in secondary and tertiary pressure ratio for any particular primary pressure ratio, than for the open primary-nozzle configuration (small diameter ratio). The open primary-nozzle configuration will, however, pump secondary and tertiary air over a wider range of secondary and tertiary pressure ratios and will start pumping at a lower primary pressure ratio. These comparisons indicate that ejector performance is not compatible with afterburner-cooling requirements, in that there is a great excess of air for the nonafterburning (closed primary nozzle) condition. Also, because the required tertiary flow is generally about one-fifth that required for the secondary system, there is a great excess of tertiary air for most conditions. As pointed out in reference 8, such an excess of tertiary air flow can be reduced by decreasing the

tertiary diameter and spacing ratios to values slightly larger than the secondary diameter and spacing ratios.

Thrust characteristics. - The effect of secondary and tertiary pressure ratio on gross thrust ratio is shown in table IV and in figures 12(a) and 12(b) for the closed and open primary-nozzle configurations, respectively. For the closed-primary nozzle, a gain in gross thrust was obtained for all primary pressure ratios, although with primary pressure ratios of 8.0 and 9.5 there was a loss in gross thrust at secondary and tertiary pressure ratios below about 1.0. These losses were as much as 4 percent and $4\frac{1}{2}$ percent, respectively, at the primary pressure ratios of 8.0 and 9.5. Data for a primary pressure ratio of 1.10 indicated that a gain in gross thrust of about 34 percent was obtainable, which was due, in most part, to the relatively large mass flow through the secondary and tertiary systems. Data for the open nozzle (fig. 12(b)) also show that a gross thrust gain is obtainable for all primary pressure ratios, with losses occurring at the low secondary and tertiary pressure ratios for primary pressure ratios of 1.10, 1.50, 4.0, and 6.0.

A comparison of figures 12(a) and 12(b) reveals the same general thrust trends that were observed in the earlier investigation of double-shroud ejectors (reference 8). These curves also follow the same general trends as the weight-flow curves in figures 10 and 11; namely, that for any given primary pressure ratio, the thrust curves for the closed primary nozzle lie above those of the open-nozzle configuration. This is due, in part, to the greater secondary and tertiary mass flows at given secondary and tertiary pressure ratios for the closed primary-nozzle configuration. Also the greater expansion ratio of the closed primary nozzle would contribute to higher thrust ratios at the high primary pressure ratios. Although the higher thrust ratios were obtained with the closed primary-nozzle configuration, it does not necessarily follow that this is the best configuration, in view of the large amount of secondary and tertiary air that is being pumped.

The sensitivity of the gross thrust ratio to changes in secondary and tertiary pressure ratio is, in general, less for the open primary-nozzle configuration. Furthermore, for each configuration this sensitivity to secondary and tertiary pressure ratio decreases as the primary pressure ratio increases.

Application of Data

As pointed out in reference 8, the performance of an ejector in an actual installation will depend upon the performance of the ejector itself as a pump and upon the performance of the cooling-air flow system for a range of operating conditions. Also, a correction must be applied to the

weight-flow ratios to take into consideration the ratio of cooling-air temperature to engine-gas temperature, as described in reference 3. However, this correction may not be valid under all conditions, particularly at the high temperature ratios; some error may therefore result, as indicated in reference 4. However, the comparisons of full-scale and model-ejector data shown in this reference are believed to show greater discrepancies than would have been the case had the configurations been exact scale models of the ejectors used. Until more complete high-temperature ejector data are available, the data presented herein should give an indication of trends to be expected from double-shroud ejectors having similar configurations and will serve as a supplement to the data contained in reference 8.

CONCLUDING REMARKS

Data obtained with a double-shroud ejector configuration, using two different size convergent primary nozzles in order to simulate a specific manufacturer's variable-area iris-type nozzle in the closed and in the open positions, indicated that the performance with the cooling-air passages blocked was typical of that for single ejectors having similar diameter and spacing ratios. Also indicated was a possible gross thrust loss of as great as 33 percent of primary-nozzle gross thrust with the primary nozzle in the closed position and with no cooling-air flow. For the open-primary-nozzle configuration and no cooling-air flow, the thrust losses were reduced to 17 percent of primary-nozzle gross thrust. For both configurations the magnitude of backflow was relatively small. There was very little interaction between the secondary and tertiary flow systems as each system was essentially unaffected by changes in flow through the other. A comparison of the pumping characteristics for both configurations indicates that, in general, the closed primary-nozzle configuration is capable of pumping more cooling air; whereas the open-nozzle configuration will pump over a greater range of secondary and tertiary pressure ratios.

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TABLE I - PERFORMANCE WITH ZERO SECONDARY AND TERTIARY FLOW

Run	Primary-stream total pressure P_1 (in. mercury absolute)	Secondary-stream total pressure P_2 (in. mercury absolute)	Tertiary-stream total pressure P_3 (in. mercury absolute)	Ambient pressure P_0 (in. mercury absolute)	Primary weight flow W_1 (lb/sec)	Secondary weight flow W_2 (lb/sec)	Tertiary weight flow W_3 (lb/sec)	Gross thrust of primary nozzle with shrouds removed F_1 (lb)	Gross thrust of ejector F_{ej} (lb)	Primary-stream total temperature T_1 (°R)	Secondary-stream total temperature T_2 (°R)	Tertiary-stream total temperature T_3 (°R)	Primary pressure ratio P_1/P_0	Secondary pressure ratio P_2/P_0	Tertiary pressure ratio P_3/P_0	Primary weight-flow ratio $W_1/\sqrt{T_1}$	Secondary weight-flow ratio $W_2/\sqrt{T_2}$	Tertiary weight-flow ratio $W_3/\sqrt{T_3}$	Gross thrust ratio F_1/F_0
Primary-nozzle position, closed																			
1	30.18	14.84	14.86	14.99	8.82	0	0	97.9	107.4	551.0	---	---	2.014	0.8867	0.8867	0	0	0	1.087
2	30.14	12.00	11.90	12.08	5.02	0	0	112.5	121.4	551.0	---	---	2.618	0.8869	0.8869	0	0	0	1.025
3	30.58	9.79	9.70	9.80	5.03	0	0	120.9	130.8	551.0	---	---	3.080	0.8869	0.8869	0	0	0	1.030
4	34.64	9.77	9.73	9.88	3.44	0	0	149.1	155.4	551.0	---	---	3.471	0.8869	0.8869	0	0	0	1.019
5	36.69	9.49	9.59	9.65	3.47	0	0	174.5	178.6	551.0	---	---	3.965	0.8864	0.8864	0	0	0	1.034
6	44.84	9.17	9.68	9.95	4.50	0	0	207.6	209.0	551.0	---	---	4.507	0.8818	0.8818	0	0	0	1.007
7	49.09	8.82	9.01	10.22	4.94	0	0	250.3	252.0	551.0	---	---	4.803	0.8798	0.8798	0	0	0	0.985
8	50.28	8.58	9.03	9.84	5.05	0	0	258.4	262.0	551.0	---	---	5.008	0.8818	0.8818	0	0	0	0.906
9	55.29	8.21	9.54	9.98	5.58	0	0	281.1	281.0	551.0	---	---	5.557	0.8821	0.8821	0	0	0	0.898
10	48.62	8.11	9.44	9.78	4.85	0	0	215.7	213.5	547.8	---	---	4.680	0.8898	0.8898	0	0	0	1.003
11	47.07	3.50	10.18	10.69	4.78	0	0	217.3	189.8	549.0	---	---	4.449	0.8804	0.8813	0	0	0	0.988
12	40.82	3.03	9.78	10.17	4.06	0	0	180.3	128.0	549.0	---	---	3.858	0.8778	0.8697	0	0	0	0.909
13	38.17	2.99	9.61	10.04	3.84	0	0	187.9	106.8	549.0	---	---	3.803	0.8878	0.8672	0	0	0	0.880
14	35.08	2.54	9.35	9.87	3.62	0	0	185.8	108.0	549.0	---	---	3.559	0.8760	0.8748	0	0	0	1.008
15	45.17	9.38	9.48	9.63	4.53	0	0	209.9	209.7	549.0	---	---	4.509	0.8818	0.8818	0	0	0	0.988
16	47.52	9.43	9.48	9.62	4.50	0	0	228.5	217.9	549.0	---	---	4.819	0.8808	0.8835	0	0	0	0.975
17	48.08	7.85	9.48	9.88	4.92	0	0	229.3	220.4	549.0	---	---	4.921	0.8847	0.8856	0	0	0	0.913
18	49.47	3.70	9.97	10.39	5.05	0	0	252.8	180.5	549.0	---	---	4.781	0.8861	0.8828	0	0	0	0.757
19	49.42	3.53	9.47	9.88	5.01	0	0	233.8	184.9	549.0	---	---	5.008	0.8874	0.8858	0	0	0	0.908
20	55.47	4.03	9.34	9.80	5.83	0	0	285.8	222.5	549.0	---	---	5.490	0.8812	0.8851	0	0	0	0.887
21	59.97	4.34	9.57	10.07	5.09	0	0	329.7	247.5	549.0	---	---	5.955	0.8858	0.8850	0	0	0	0.850
22	60.92	4.74	9.15	9.77	6.85	0	0	327.8	285.1	549.0	---	---	6.747	0.8858	0.8858	0	0	0	0.896
23	70.87	5.00	9.15	9.82	7.13	0	0	348.1	313.4	549.0	---	---	7.126	0.8802	0.8818	0	0	0	0.870
24	70.17	5.01	8.40	9.80	7.10	0	0	354.8	317.1	549.0	---	---	7.627	0.8858	0.8858	0	0	0	0.894
25	70.47	5.33	8.02	9.28	7.88	0	0	354.5	350.8	549.0	---	---	8.135	0.8844	0.8844	0	0	0	0.880
26	78.57	5.31	8.62	8.60	7.88	0	0	367.8	365.4	549.0	---	---	8.867	0.8847	0.8853	0	0	0	0.880
27	75.97	5.36	8.43	8.10	7.88	0	0	390.4	358.3	549.0	---	---	9.330	0.8844	0.8844	0	0	0	0.880
28	75.97	5.28	8.46	7.80	7.88	0	0	384.9	359.8	549.0	---	---	9.740	0.8844	0.8844	0	0	0	0.880
29	77.57	8.56	8.89	7.57	7.61	0	0	405.1	369.7	549.0	---	---	10.82	0.8844	0.8844	0	0	0	0.880
30	32.77	9.41	9.38	9.85	5.30	0	0	140.9	145.0	549.0	---	---	3.628	0.8843	0.8843	0	0	0	0.880
31	29.97	9.41	9.77	9.97	3.08	0	0	125.1	128.1	549.0	---	---	3.008	0.8843	0.8843	0	0	0	0.880
Primary-nozzle position, open																			
1	29.85	26.01	27.05	27.25	3.98	0	0	48.4	44.08	539.0	---	---	1.099	0.9642	0.9644	0	0	0	0.948
2	30.08	22.07	23.42	24.11	5.25	0	0	55.2	50.59	539.0	---	---	1.248	0.9154	0.9154	0	0	0	0.888
3	28.95	17.47	19.88	19.91	5.00	0	0	142.7	125.8	537.0	---	---	1.503	0.8774	0.8774	0	0	0	0.888
4	30.43	14.41	18.77	17.12	5.98	0	0	178.6	167.8	537.0	---	---	1.788	0.8417	0.8417	0	0	0	0.864
5	30.13	12.06	16.16	15.80	5.94	0	0	190.7	178.6	536.0	---	---	1.844	0.7774	0.7774	0	0	0	0.841
6	30.13	11.14	14.78	15.18	5.88	0	0	184.6	178.8	536.0	---	---	1.891	0.7845	0.7845	0	0	0	0.820
7	30.18	8.87	14.48	14.63	5.85	0	0	198.8	188.0	536.0	---	---	2.081	0.8800	0.8800	0	0	0	0.853
8	30.85	5.48	12.18	12.42	5.84	0	0	206.9	178.8	534.0	---	---	2.253	0.8845	0.8845	0	0	0	0.873
9	30.85	5.37	11.83	11.90	5.82	0	0	218.9	197.7	534.0	---	---	2.588	0.8813	0.8813	0	0	0	0.800
10	30.88	5.34	9.53	10.10	5.85	0	0	228.8	218.9	536.0	---	---	2.878	0.8867	0.8867	0	0	0	0.821
11	40.08	6.88	9.88	9.83	7.88	0	0	348.2	333.9	539.0	---	---	4.058	0.8867	0.8867	0	0	0	0.838
12	48.85	6.84	9.89	9.84	8.88	0	0	465.8	444.4	540.0	---	---	5.025	0.8812	0.8812	0	0	0	0.896
13	54.43	9.27	9.26	10.18	10.88	0	0	500.5	498.9	540.0	---	---	6.247	0.8804	0.8804	0	0	0	0.898
14	54.43	9.21	8.55	8.84	10.88	0	0	512.8	498.4	540.0	---	---	6.072	1.028	0.8804	0	0	0	0.898
15	54.85	8.28	8.85	8.18	10.78	0	0	523.5	506.2	541.0	---	---	6.703	1.181	1.081	0	0	0	0.871
16	54.85	8.23	7.48	10.78	10.78	0	0	531.1	519.7	541.0	---	---	7.573	1.258	1.028	0	0	0	0.874
17	58.03	5.88	8.23	8.70	10.80	0	0	559.2	531.1	541.0	---	---	8.213	1.368	0.8781	0	0	0	0.880
18	58.03	5.84	8.10	10.77	10.77	0	0	544.8	540.4	541.0	---	---	9.081	1.815	1.311	0	0	0	0.881
19	58.85	9.34	8.48	8.34	10.88	0	0	577.7	568.7	541.0	---	---	10.82	1.733	1.287	0	0	0	0.881
20	58.43	9.34	8.48	10.88	10.88	0	0	589.7	560.3	541.0	---	---	11.34	1.698	0.8858	0	0	0	1.001
21	58.85	9.38	8.40	10.88	10.88	0	0	538.2	525.1	541.0	---	---	7.089	1.190	0.8854	0	0	0	0.875
22	58.75	9.36	8.39	8.30	10.88	0	0	538.0	520.5	540.0	---	---	8.714	1.127	0.8819	0	0	0	0.871
23	58.88	9.35	8.35	8.30	10.88	0	0	508.4	484.1	540.0	---	---	8.415	1.078	0.8811	0	0	0	0.875
24	58.50	9.01	8.88	8.81	10.41	0	0	501.8	487.7	540.0	---	---	8.068	1.025	0.8808	0	0	0	0.871
25	55.08	8.99	8.63	9.71	10.38	0	0	480.4	443.3	538.5	---	---	5.457	0.8808	0.8808	0	0	0	0.860
26	53.13	9.10	9.96	10.62	10.38	0	0	488.4	478.8	538.5	---	---	4.888	0.8845	0.8845	0	0	0	0.861
27	53.85	9.18	11.18	10.39	10.39	0	0	475.8	463.8	538.5	---	---	4.580	0.8845	0.8845	0	0	0	0.860
28	53.13	9.17	13.14	13.68	10.36	0	0	484.7	443.0	538.5	---	---	3.901	0.8733	0.8848	0	0	0	0.843
29	40.83	7.08	11.64	11.90	7.80	0	0	389.8	314.3	538.5	---	---	3.341	0.8835	0.8835	0	0	0	0.851
30	40.15	7.08	14.11	14.44	7.41	0	0	306.0	290.8	538.5	---	---	2.778	0.8896	0.8896	0	0	0	0.890
31	30.18	6.47	13.28	13.28	5.80	0	0	310.4	188.8	538.5	---	---	2.878	0.8819	0.8819	0	0	0	0.885
32	30.18	6.18	14.48	14.88	5.81	0	0	188.9	188.7	538.5	---	---	2.087	0.8817	0.8817	0	0	0	0.847
33	30.15	11.67	15.21	15.38	5.81	0	0	192.0	181.5	538.5	---	---	1.982	0.8846	0.8846	0	0	0	0.844
34	30.18	14.81	14.85	17.20	5.80	0	0	174.1	185.0	538.5	---	---	1.788	0.8846	0.8846	0	0	0	0.847
35	30.83	8.48	14.72	16.19	5.80	0	0	184.7	181.4	538.5	---	---	1.980	0.8846	0.8846	0	0	0	0.848

*Values obtained from nozzle calibration.

TABLE II - EFFECT OF PRIMARY PRESSURE RATIO ON BACKFLOW

Run	Primary-stream total pressure P_p (in. mercury absolute)	Secondary-stream total pressure P_s (in. mercury absolute)	Tertiary-stream total pressure P_t (in. mercury absolute)	Ambient exhaust pressure P_0 (in. mercury absolute)	Primary weight flow W_p (lb/sec)	Secondary weight flow W_s (lb/sec)	Tertiary weight flow W_t (lb/sec)	Gross thrust of primary nozzle with shrouds removed F_j (lb)	Gross thrust of ejector F_e (lb)	Primary-stream total temperature T_p ($^{\circ}R$)	Secondary-stream total temperature T_s ($^{\circ}R$)	Tertiary-stream total temperature T_t ($^{\circ}R$)	Primary pressure ratio P_p/P_0	Secondary pressure ratio P_s/P_0	Tertiary pressure ratio P_t/P_0	Secondary weight-flow ratio $W_s/W_p \sqrt{T_p/T_s}$	Tertiary weight-flow ratio $W_t/W_p \sqrt{T_p/T_t}$	Gross-thrust ratio $F_{e,j}/F_j$	
						(a)	(a)	(b)									(a)	(a)	
Primary-nozzle position, closed																			
1	30.21	28.68	28.70	28.81	1.72	-0.00111	0.00111	24.84	24.17	538.0	540.0	542.0	1.127	0.8962	0.8959	-0.00085	0.00065	0.8807	
2	29.71	23.71	23.76	25.87	2.20	-0.00248	0.00248	40.70	41.85	538.0	541.0	541.0	1.245	.8933	.8954	-0.00115	.00215	1.081	
3	29.81	19.58	19.64	19.78	2.87	-0.00387	0.00387	68.00	72.52	538.0	542.0	541.0	1.512	.8999	.8929	-0.00145	.00145	1.085	
4	29.88	17.07	17.17	17.29	2.78	-0.00364	0.00364	82.86	90.30	538.0	542.0	541.0	1.727	.8973	.8951	-0.00131	.00131	1.092	
5	30.11	14.66	14.97	15.06	4.98	-0.00382	0.00382	97.05	104.5	538.0	542.0	540.0	1.897	.8854	.8927	-0.00112	.00212	1.077	
6	29.81	11.78	11.84	11.95	2.97	-0.00244	0.00244	112.6	122.3	538.0	542.0	540.0	2.498	.8858	.8908	-0.00082	.00082	1.086	
7	29.81	9.92	10.0	10.10	2.97	-0.00251	0.00251	122.2	128.0	538.0	542.0	538.0	2.981	.8822	.8801	-0.00084	.00084	1.048	
8	40.31	9.39	9.59	9.86	4.00	-0.00182	0.00182	182.3	188.1	538.0	543.0	538.0	4.092	.8633	.8738	-0.00040	.00040	1.038	
9	50.06	8.01	9.80	10.03	5.08	-0.00706	0.00706	256.7	288.2	538.0	542.0	536.0	4.891	.7986	.8671	-0.00159	.00159	.9839	
10	60.16	4.79	9.15	9.82	6.09	-0.0121	-0.0121	294.9	288.8	538.0	542.0	531.0	6.128	.4878	.8318	-0.00198	.00198	.8775	
11	70.66	5.39	9.09	10.01	7.12	-0.0118	-0.0118	352.9	319.2	538.0	542.0	532.0	7.049	.5385	.8081	-0.00168	.00168	.9044	
12	78.81	5.96	8.21	9.88	7.88	-0.00788	-0.00788	400.3	384.7	538.0	543.0	530.0	7.989	.6018	.8301	-0.00085	.00085	.9108	
13	78.81	5.78	6.37	8.87	8.08	-0.00589	-0.00589	409.2	373.3	538.0	543.0	528.0	8.875	.6444	.7101	-0.00089	.00089	.9121	
14	80.01	5.68	5.21	8.14	8.12	-0.00408	-0.00408	415.4	386.1	538.0	543.0	527.0	9.829	.6819	.8400	-0.00050	.00050	.9293	
15	79.78	5.60	4.99	7.78	8.10	-0.00524	-0.00524	415.7	385.4	538.0	542.0	526.0	10.28	.7088	.8450	-0.00085	.00085	.9270	
Primary-nozzle position, open																			
16	30.03	28.10	27.01	27.18	3.98	0.0184	-0.0184	49.06	44.79	580.0	548.0	543.0	1.108	0.9803	0.8937	0.0039	-0.0039	0.8131	
17	30.08	22.58	23.90	24.20	5.15	-0.0188	-0.0188	92.25	88.89	548.0	547.0	543.0	1.243	.8240	.8978	.0036	-0.0036	.8640	
18	29.98	17.90	19.84	20.20	5.75	-0.0190	-0.0190	138.1	128.7	547.0	548.0	543.0	1.484	.8861	.8928	.0035	-0.0035	.9282	
19	29.89	14.85	16.89	17.28	5.78	-0.0179	-0.0179	170.2	182.1	548.0	544.0	543.0	1.731	.8592	.8788	.0031	-0.0031	.9522	
20	30.03	11.89	14.71	15.08	5.81	-0.0188	-0.0188	193.8	182.0	548.0	543.0	543.0	1.991	.7886	.8755	.0032	-0.0032	.9391	
21	30.13	8.84	13.41	13.78	6.80	-0.0244	-0.0244	206.7	180.6	548.0	541.0	543.0	2.187	.4819	.8731	.0042	-0.0042	.8782	
22	30.08	6.28	11.89	11.89	5.81	-0.0205	-0.0205	219.0	202.6	548.0	541.0	543.0	2.530	.5282	.8748	.0035	-0.0035	.9248	
23	29.93	6.05	9.74	10.04	5.77	-0.0182	-0.0182	254.4	221.1	548.0	538.0	543.0	2.981	.6028	.8701	.0028	-0.0028	.9435	
24	40.23	7.53	9.81	10.01	7.79	-0.0125	-0.0125	347.3	337.7	548.0	538.0	543.0	4.019	.7522	.8600	.0018	-0.0018	.9721	
25	49.83	9.78	9.48	10.07	9.70	-0.0058	-0.0058	431.4	441.5	548.0	538.0	542.0	4.948	.8699	.8594	.0006	-0.0006	.9784	
26	50.43	8.42	8.88	8.18	9.82	-0.0079	-0.0079	475.4	478.8	548.0	527.0	542.0	6.185	1.029	.8142	-0.0008	.0008	.9948	
27	48.53	8.30	8.28	8.89	9.45	0	0	448.3	441.5	548.0	538.0	542.0	5.409	.9232	.8210	0	0	.9848	
28	50.53	8.32	5.27	7.35	9.80	-0.0108	-0.0108	482.1	470.0	548.0	538.0	542.0	6.865	1.138	.7190	-0.0011	.0011	.9751	
29	50.33	8.29	4.88	6.43	9.81	-0.0108	-0.0108	480.4	481.3	548.0	538.0	542.0	7.827	1.289	.7278	-0.0011	.0011	.9812	
30	50.23	8.28	5.84	5.40	9.81	-0.0118	-0.0118	488.8	485.6	548.0	538.0	542.0	9.302	1.580	1.025	-0.0012	.0012	.9835	

* Negative values indicate backflow.

b Values obtained from nozzle calibration.

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TABLE III - INTERACTION OF SECONDARY AND TERTIARY SYSTEMS

Run	Primary stream total pressure P_p (in. mercury absolute)	Secondary stream total pressure P_s (in. mercury absolute)	Tertiary stream total pressure P_t (in. mercury absolute)	Ambient exhaust pressure P_0 (in. mercury absolute)	Primary weight flow \dot{W}_p (lb/sec)	Secondary weight flow \dot{W}_s (lb/sec)	Tertiary weight flow \dot{W}_t (lb/sec)	Gross thrust of primary nozzle with shrouds removed F_j (lb)	Gross thrust of ejector F_{ej} (lb)	Primary stream total temperature T_p (°R)	Secondary stream total temperature T_s (°R)	Tertiary stream total temperature T_t (°R)	Primary pressure ratio P_p/P_0	Secondary pressure ratio P_s/P_0	Tertiary pressure ratio P_t/P_0	Secondary weight flow ratio $\frac{\dot{W}_s}{\dot{W}_p} \sqrt{\frac{T_p}{T_s}}$	Tertiary weight flow ratio $\frac{\dot{W}_t}{\dot{W}_p} \sqrt{\frac{T_p}{T_t}}$	Gross thrust ratio F_j/F_p
Primary-nozzle position, closed																		
1	29.96	13.03	10.02	10.0	5.04	0.581	0.068	122.9	127.3	539.0	534.0	530.0	2.998	1.305	1.002	0.1802	0.0189	1.036
2	29.91	13.02	10.11	10.0	5.03	.584	.132	122.7	126.8	539.5	535.5	535.0	2.991	1.302	1.011	.1920	.0453	1.032
3	29.91	13.03	10.27	10.0	5.03	.584	.199	122.6	126.8	540.5	537.5	536.0	2.991	1.303	1.027	.1922	.0854	1.026
4	29.96	13.02	10.82	10.0	5.03	.586	.272	122.9	128.7	541.0	539.5	537.5	2.986	1.302	1.032	.1930	.0896	1.047
5	29.86	13.04	10.85	10.02	5.03	.588	.342	122.3	127.3	548.0	539.0	537.5	2.980	1.301	1.031	.1936	.1124	1.041
6	29.86	13.02	11.89	10.0	5.03	.587	.456	122.4	133.0	548.0	539.5	538.0	2.988	1.302	1.189	.1935	.1499	1.037
7	29.78	10.07	13.03	10.01	3.02	.275	.597	121.7	133.0	548.5	540.5	539.5	2.973	1.000	1.302	.0909	.1972	1.093
8	29.86	10.28	13.03	10.0	3.02	.317	.595	122.3	134.4	544.5	540.5	539.5	2.988	1.028	1.303	.1048	.1941	1.099
9	29.86	10.99	13.04	10.0	3.02	.487	.596	122.3	137.0	548.0	541.0	540.5	2.986	1.099	1.304	.1409	.1975	1.122
10	29.86	13.18	13.05	10.01	3.02	.592	.597	122.3	135.1	548.5	542.5	540.5	2.983	1.317	1.304	.1965	.1968	1.106
11	29.96	9.77	13.01	9.87	5.03	.250	.599	123.1	133.7	546.0	542.0	540.5	3.005	.9799	1.305	.0822	.1947	1.086
12	29.88	9.33	13.03	9.99	3.02	.137	.609	122.4	132.8	548.0	542.0	541.5	2.989	.9339	1.304	.0452	.2009	1.02
Primary-nozzle position, open																		
13	30.12	13.01	10.00	9.88	5.89	0.577	0.0647	257.0	250.3	540.5	541.0	538.0	3.018	1.304	1.002	0.0980	0.0111	1.056
14	30.02	13.05	10.11	10.03	5.89	.591	.1298	256.3	248.8	548.5	545.5	541.5	2.995	1.301	1.008	.1005	.0220	1.037
15	29.87	13.05	10.03	10.01	5.89	.589	.0784	255.0	249.8	542.0	548.5	542.0	2.994	1.304	1.002	.1003	.0150	1.032
16	30.12	13.03	10.21	10.01	5.88	.589	.1961	256.8	251.0	542.0	547.0	543.5	3.009	1.302	1.020	.1006	.0333	1.080
17	29.82	13.04	10.59	10.01	5.87	.590	.2478	254.8	249.8	542.5	547.0	544.0	2.989	1.303	1.037	.1009	.0422	1.084
18	29.87	13.03	10.82	9.99	5.82	.589	.3060	258.2	251.0	541.0	547.0	544.5	3.000	1.304	1.065	.1017	.0886	1.057
19	30.02	13.01	11.17	10.0	5.83	.588	.3991	258.8	254.8	541.0	547.0	544.0	3.002	1.301	1.117	.1010	.0884	1.090
20	30.12	13.05	13.05	10.01	5.87	.588	.6270	258.8	245.1	541.3	547.5	544.0	3.009	1.304	1.305	.1009	.1070	1.111
21	30.04	9.88	12.25	9.87	5.84	.235	.581	258.1	248.9	548.0	542.0	544.0	3.013	.9990	1.299	.0435	.1113	1.054
22	30.09	10.49	13.00	9.96	5.84	.304	.587	258.8	251.0	544.0	544.0	548.0	3.015	1.051	1.303	.0580	.1108	1.081
23	30.09	11.10	13.00	9.98	5.85	.368	.541	256.8	253.1	548.0	544.5	548.0	3.015	1.112	1.303	.0828	.1096	1.059
24	30.09	11.81	13.00	9.99	5.84	.448	.831	256.8	258.7	548.5	548.0	547.0	3.012	1.182	1.301	.0768	.1077	1.086
25	30.09	12.35	13.00	9.98	5.84	.507	.828	256.8	257.4	547.0	547.0	547.6	3.015	1.237	1.305	.0848	.1072	1.088
26	30.14	13.04	13.00	9.98	5.80	.587	.817	257.2	260.9	547.0	549.0	548.0	3.020	1.307	1.305	.1014	.1068	1.100
27	30.14	13.45	13.01	9.99	5.85	.681	.812	257.0	262.4	547.0	549.5	548.0	3.017	1.346	1.302	.1115	.1047	1.107

*Values obtained from nozzle calibration.

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TABLE IV - ENGINE PERFORMANCE

Run	Primary stagnation pressure P_0 (in. mercury absolute)	Secondary stagnation pressure P_2 (in. mercury absolute)	Tertiary stagnation pressure P_3 (in. mercury absolute)	Subsonic stagnation pressure P_0 (in. mercury absolute)	Primary weight flow \dot{W}_p (lb/sec)	Secondary weight flow \dot{W}_s (lb/sec)	Tertiary weight flow \dot{W}_t (lb/sec)	Gross weight flow of pri- mary nozzle with shroud removed \dot{W}_j (lb) (a)	Gross weight flow of sec- ondary nozzle \dot{W}_s (lb)	Primary stagnation temperature T_0 (°R)	Secondary stagnation temperature T_2 (°R)	Tertiary stagnation temperature T_3 (°R)	Primary pressure ratio P_0/P_2	Secondary pressure ratio P_2/P_3	Tertiary pressure ratio P_3/P_0	Secondary weight- flow ratio \dot{W}_s/\dot{W}_p	Tertiary weight- flow ratio \dot{W}_t/\dot{W}_p	Cross- stream ratio \dot{W}_s/\dot{W}_t	
Primary-nozzle position, closed																			
1	30.07	27.18	27.20	27.18	1.88	0.145	0.087	20.59	22.75	536.0	539.5	539.5	1.108	1.000	1.001	0.0864	0.0680	1.089	
2	30.28	27.49	27.42	27.58	1.87	.807	.144	20.59	21.35	547.0	540.5	541.5	1.104	1.001	1.001	.1233	.0858	1.036	
3	30.07	27.38	27.37	27.39	1.88	.849	.181	20.08	20.82	545.0	541.5	541.5	1.102	1.003	1.003	.1485	.1086	1.067	
4	30.08	27.40	27.40	27.40	1.88	.858	.201	19.80	21.35	548.0	542.0	544.5	1.100	1.004	1.004	.1714	.1327	1.088	
5	29.87	27.47	27.47	27.57	1.88	.835	.285	19.15	22.04	548.5	543.5	545.0	1.098	1.007	1.007	.1985	.1579	1.131	
6	29.87	27.61	27.61	27.50	1.84	.408	.328	19.18	21.35	549.0	544.0	544.0	1.088	1.011	1.011	.2440	.1883	1.115	
7	29.87	27.59	27.59	27.50	1.85	.824	.430	19.18	24.49	549.0	545.0	547.5	1.088	1.021	1.022	.3108	.2556	1.229	
8	29.87	28.06	28.11	27.58	1.85	.845	.507	19.18	25.80	549.0	545.0	545.0	1.088	1.030	1.033	.3828	.3015	1.359	
9	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
10	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
11	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
12	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
13	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
14	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
15	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
16	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
17	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
18	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
19	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
20	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
21	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
22	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
23	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
24	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
25	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
26	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
27	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
28	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
29	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
30	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
31	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
32	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
33	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
34	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
35	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
36	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
37	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
38	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
39	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
40	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
41	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
42	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
43	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
44	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
45	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
46	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
47	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
48	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
49	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
50	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
51	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
52	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
53	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
54	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
55	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
56	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	545.0	545.0	1.088	1.001	1.001	.0801	.0881	1.108	
57	29.87	30.04	30.08	30.02	1.87	.181	.078	20.08	20.82	549.0	5								

TABLE IV - Concluded. EJECTOR PERFORMANCE

Run	Primary stream total pressure P_0 (in. mercury absolute)	Secondary stream total pressure P_2 (in. mercury absolute)	Tertiary stream total pressure P_3 (in. mercury absolute)	Ambient exhaust pressure P_4 (in. mercury absolute)	Primary weight flow W_1 (lb/sec)	Secondary weight flow W_2 (lb/sec)	Tertiary weight flow W_3 (lb/sec)	Gross thrust of primary nozzle with shrouds removed F_1 (lb)	Gross thrust of ejector F_2 (lb)	Primary stream total temperature T_0 (°F)	Secondary stream total temperature T_2 (°F)	Tertiary stream total temperature T_3 (°F)	Primary pressure ratio P_0/P_2	Secondary pressure ratio P_2/P_3	Tertiary pressure ratio P_3/P_4	Secondary weight flow ratio W_2/W_1	Tertiary weight flow ratio W_3/W_1	Gross thrust ratio F_2/F_1	
Primary nozzle position, open																			
1	30.19	27.08	27.08	27.12	3.80	0.250	0	82.84	44.3	555.0	549.0	549.0	1.115	0.999	0.999	0.0482	0	0.8753	
2	30.19	27.19	27.19	27.16	3.54	0.305	0.129	82.84	44.3	555.0	549.0	549.0	1.115	1.001	1.001	0.0482	0.0543	0.8530	
3	30.04	27.17	27.17	27.10	3.44	0.345	0.184	80.98	44.8	554.0	550.0	551.0	1.108	1.005	1.005	0.0482	0.0482	0.8530	
4	30.04	27.31	27.31	27.18	3.53	0.384	0.244	78.71	44.9	554.8	551.0	552.0	1.113	1.006	1.006	0.0482	0.0654	0.8637	
5	30.08	27.38	27.38	27.10	3.50	0.454	0.384	71.54	47.6	555.0	552.0	553.0	1.110	1.006	1.006	0.0482	0.0785	0.8637	
6	30.08	27.46	27.46	27.14	3.83	0.508	0.533	70.54	48.5	555.5	552.0	553.0	1.109	1.005	1.005	0.0482	0.0948	0.8637	
7	29.99	27.64	27.64	27.10	3.50	0.607	0.417	69.78	50.5	555.5	553.8	554.5	1.107	1.000	1.000	0.0482	0.1015	0.8637	
8	29.99	27.81	27.81	27.04	3.54	0.644	0	241.7	137.3	549.0	549.0	549.0	1.500	0.999	0.999	0.0482	0.0482	0.8637	
9	30.19	28.04	28.04	28.00	3.58	0.598	0.131	144.4	140.1	550.0	550.0	550.0	1.000	1.000	1.000	0.0482	0.0482	0.8637	
10	30.14	28.11	28.11	28.08	3.55	0.558	0.182	143.1	140.8	550.0	551.0	551.0	1.506	1.004	1.004	0.0482	0.0482	0.8637	
11	30.04	28.15	28.15	28.14	3.83	0.494	0.184	143.3	142.8	551.0	552.0	552.0	1.507	1.011	1.011	0.0482	0.0482	0.8637	
12	30.08	28.38	28.38	28.01	3.85	0.588	0.318	143.5	143.8	551.0	552.0	552.0	1.504	1.015	1.015	0.0482	0.0482	0.8637	
13	30.04	28.58	28.58	28.00	3.54	0.638	0.387	143.4	145.9	551.0	553.0	553.0	1.508	1.028	1.028	0.0482	0.0482	0.8637	
14	30.04	28.84	28.84	28.01	3.50	0.750	0.468	141.6	150.0	551.0	553.0	554.0	1.501	1.047	1.047	0.0482	0.0482	0.8637	
15	29.99	21.45	21.45	20.0	3.52	0.889	0.638	141.7	154.3	552.0	553.0	554.0	1.500	1.042	1.042	0.0482	0.0482	0.8637	
16	29.99	21.45	21.45	18.08	3.52	0.912	0	129.8	151.3	552.0	553.0	554.0	1.998	0.997	0.997	0.0482	0.0482	0.8637	
17	30.14	18.09	18.09	18.06	3.53	0.935	0.167	144.6	154.6	552.0	554.0	554.0	2.001	1.002	1.002	0.0482	0.0482	0.8637	
18	30.04	15.11	15.11	14.08	3.56	0.401	0.184	144.4	154.6	552.0	554.0	554.0	2.004	1.015	1.015	0.0482	0.0482	0.8637	
19	30.14	15.28	15.28	15.05	3.84	0.472	0.324	134.9	158.4	551.0	554.0	554.0	2.005	1.015	1.015	0.0482	0.0482	0.8637	
20	30.14	15.58	15.58	15.05	3.58	0.568	0.324	134.9	161.9	551.0	555.0	555.0	2.006	1.028	1.028	0.0482	0.0482	0.8637	
21	30.14	15.80	15.80	15.02	3.84	0.623	0.381	138.3	161.3	551.0	555.0	555.0	2.007	1.032	1.032	0.0482	0.0482	0.8637	
22	30.04	16.48	16.48	15.01	3.88	0.648	0.381	138.8	161.9	552.0	555.0	555.0	2.016	1.034	1.034	0.0482	0.0482	0.8637	
23	30.14	17.34	17.34	14.94	3.88	0.698	0.480	138.7	162.5	552.0	555.0	555.0	2.017	1.034	1.034	0.0482	0.0482	0.8637	
24	30.04	18.18	18.18	14.85	3.85	0.721	0.484	138.2	163.5	552.0	555.0	555.0	2.005	1.079	1.079	0.0482	0.0482	0.8637	
25	30.07	9.79	9.79	9.39	3.84	0.232	0	358.3	358.9	549.0	544.5	538.5	2.010	0.970	0.970	0.0482	0.0482	0.8637	
26	30.02	10.09	10.10	10.02	3.52	0.280	0.150	355.4	340.5	549.0	544.0	544.0	2.008	1.007	1.007	0.0482	0.0482	0.8637	
27	30.12	10.19	10.20	10.05	3.82	0.271	0.197	355.5	340.3	549.0	548.0	548.0	2.005	1.016	1.016	0.0482	0.0482	0.8637	
28	30.02	10.41	10.41	10.02	3.85	0.297	0.268	355.6	341.0	549.0	547.5	547.5	2.006	1.028	1.028	0.0482	0.0482	0.8637	
29	30.19	10.75	10.75	10.01	3.82	0.288	0.269	355.8	344.4	549.0	548.0	548.0	2.009	1.072	1.072	0.0482	0.0482	0.8637	
30	30.08	11.39	11.39	10.02	3.85	0.348	0.348	355.8	344.4	549.0	549.0	549.0	2.008	1.137	1.137	0.0482	0.0482	0.8637	
31	30.07	12.15	12.15	10.01	3.86	0.443	0.387	355.9	346.0	549.0	550.0	550.0	2.003	1.214	1.214	0.0482	0.0482	0.8637	
32	30.08	13.58	13.40	10.01	3.96	0.439	0.550	356.8	346.0	549.0	551.0	551.0	2.009	1.337	1.337	0.0482	0.0482	0.8637	
33	30.02	9.53	9.62	9.0	3.84	0.082	0	347.5	343.4	552.0	550.0	551.0	4.022	0.985	0.985	0.0482	0.0482	0.8637	
34	30.07	10.21	10.10	10.05	3.84	0.196	0.196	346.5	344.3	552.0	551.0	551.0	3.996	1.008	1.007	0.0482	0.0482	0.8637	
35	30.12	10.37	10.37	10.0	3.81	0.185	0.281	344.0	344.3	552.0	551.0	551.0	4.018	1.007	1.007	0.0482	0.0482	0.8637	
36	30.18	10.67	10.65	10.03	3.81	0.158	0.297	344.5	344.1	552.0	551.0	551.0	4.011	1.006	1.006	0.0482	0.0482	0.8637	
37	30.05	11.06	11.06	10.01	3.86	0.196	0.379	347.0	341.2	552.0	551.0	551.0	4.021	1.014	1.014	0.0482	0.0482	0.8637	
38	30.00	11.69	11.68	10.02	3.82	0.112	0.480	344.5	344.2	552.0	551.0	551.0	4.018	1.117	1.117	0.0482	0.0482	0.8637	
39	30.05	12.33	12.33	9.99	3.82	0.121	0.525	345.9	345.3	552.0	552.0	552.0	4.009	1.224	1.224	0.0482	0.0482	0.8637	
40	30.00	12.69	12.71	10.03	3.86	0.139	0.645	346.6	347.9	552.0	552.0	552.0	4.012	1.368	1.368	0.0482	0.0482	0.8637	
41	30.00	13.04	13.04	10.01	3.87	0.178	0.675	346.8	348.9	552.0	552.0	552.0	4.018	1.503	1.503	0.0482	0.0482	0.8637	
42	30.00	13.49	13.49	10.03	3.87	0.200	0.698	346.8	349.0	552.0	552.0	552.0	4.003	1.586	1.586	0.0482	0.0482	0.8637	
43	30.00	13.84	13.88	10.00	3.81	0.229	0.723	347.0	349.3	552.0	553.0	553.0	4.000	1.684	1.684	0.0482	0.0482	0.8637	
44	30.00	13.84	13.90	10.02	3.82	0.247	0.811	346.8	349.7	552.0	554.0	554.0	4.018	1.735	1.735	0.0482	0.0482	0.8637	
45	30.00	9.43	9.44	9.0	3.84	0.108	0.178	349.5	345.3	552.0	552.0	552.0	6.087	1.028	1.028	0.0482	0.0482	0.8637	
46	30.04	10.27	10.28	9.18	3.82	0.092	0.275	349.3	345.3	552.0	552.0	552.0	6.081	1.119	1.119	0.0482	0.0482	0.8637	
47	30.04	10.47	10.48	9.18	3.82	0.092	0.319	349.3	345.3	552.0	552.0	552.0	6.088	1.149	1.149	0.0482	0.0482	0.8637	
48	30.00	11.42	11.45	9.17	3.82	0.098	0.381	349.5	347.4	552.0	552.0	552.0	6.081	1.245	1.245	0.0482	0.0482	0.8637	
49	30.00	12.40	12.40	9.18	3.82	0.081	0.478	349.7	349.5	552.0	552.0	552.0	6.048	1.381	1.381	0.0482	0.0482	0.8637	
50	30.16	12.86	12.86	9.17	3.82	0.101	0.515	349.5	349.1	552.0	552.0	552.0	6.014	1.401	1.401	0.0482	0.0482	0.8637	
51	30.00	13.86	13.91	9.17	3.82	0.154	0.603	349.5	349.8	552.0	552.0	552.0	6.031	1.514	1.514	0.0482	0.0482	0.8637	
52	30.00	14.70	14.74	9.17	3.82	0.206	0.687	349.7	349.7	552.0	552.0	552.0	6.031	1.603	1.603	0.0482	0.0482	0.8637	
53	30.16	9.36	9.39	9.0	3.82	0.082	0.288	349.8	349.8	552.0	548.0	548.0	6.497	1.614	1.614	0.0482	0.0482	0.8637	
54	30.16	10.28	10.29	9.0	3.82	0.082	0.348	349.8	349.8	552.0	548.0	548.0	6.494	1.782	1.782	0.0482	0.0482	0.8637	
55	30.16	10.87	10.88	9.0	3.82	0.082	0.394	349.8	349.8	552.0	548.0	548.0	6.494	1.874	1.874	0.0482	0.0482	0.8637	
56	30.23	11.71	11.70	9.0	3.82	0.082	0.461	349.7	349.8	552.0	548.0	548.0	6.508	2.015	2.014	0.0482	0.0482	0.8637	
57	30.15	12.87	12.85	9.0	3.82	0.082	0.528	349.7	349.4	548.0	548.0	548.0	6.508	2.184	2.180	0.0482	0.0482	0.8637	
58	30.16	12.85	12.81	9.0	3.82	0.082	0.609	349.8	349.4	548.0	548.0	548.0	6.497	2.377	2.370	0.0482	0.0482	0.8637	
59	30.25	13.80	13.81	9.0	3.82	0.082	0.683	349.8	349.4	548.0	548.0	548.0	6.508	2.548	2.547	0.0482	0.0482	0.8637	
60	30.28	14.30	14.43	9.0	3.82	0.082	0.807	349.8	349.4	548.0	548.0	548.0	6.508	2.846	2.846	0.0482	0.0482	0.8637	
61	30.35	9.39	9.37	9.0	3.82	0.082	0.774	349.4	349.9	547.0	548.0	547.0	6.507	1.871	1.871	0.0482	0.0482	0.8637	
62	3																		

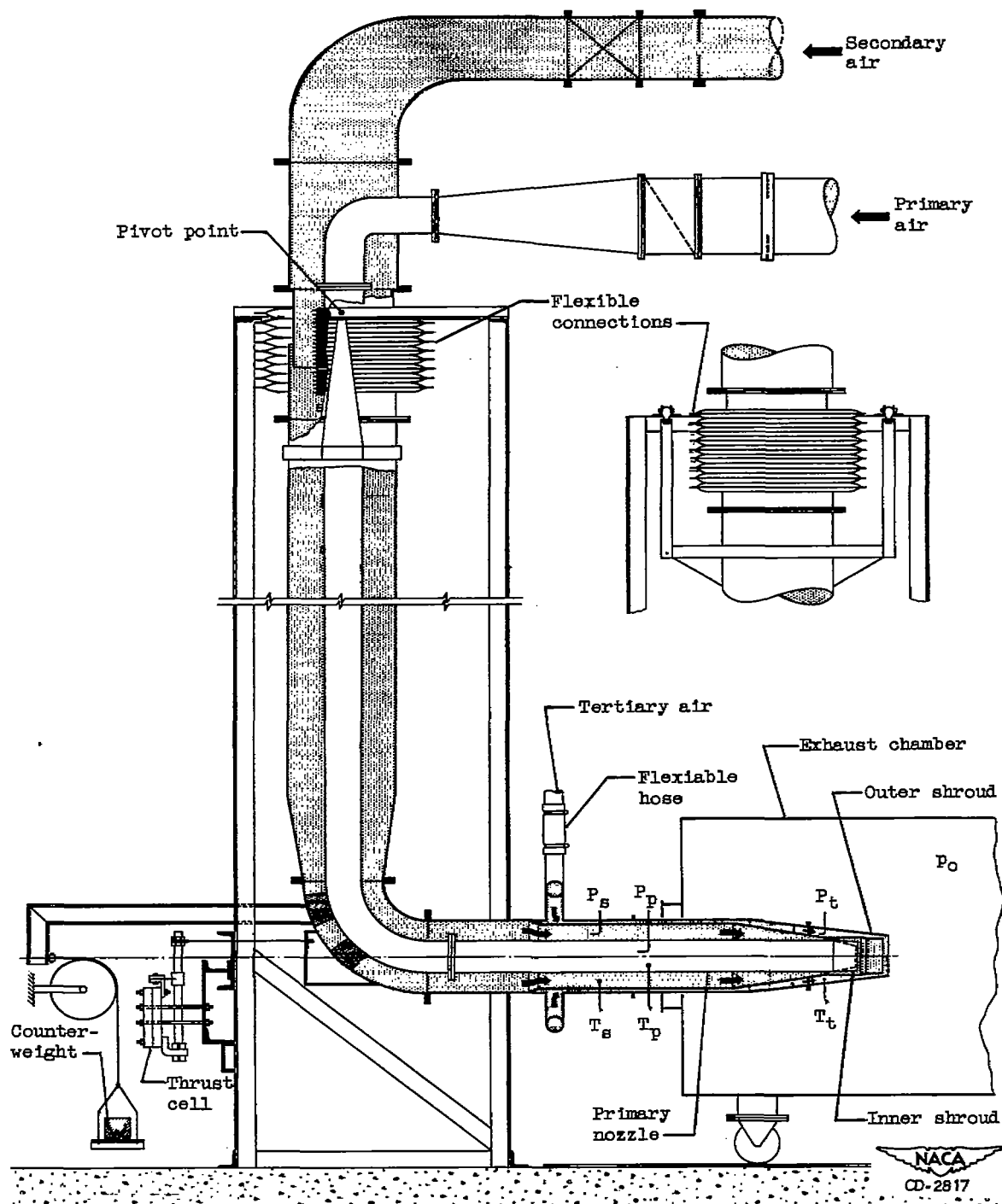
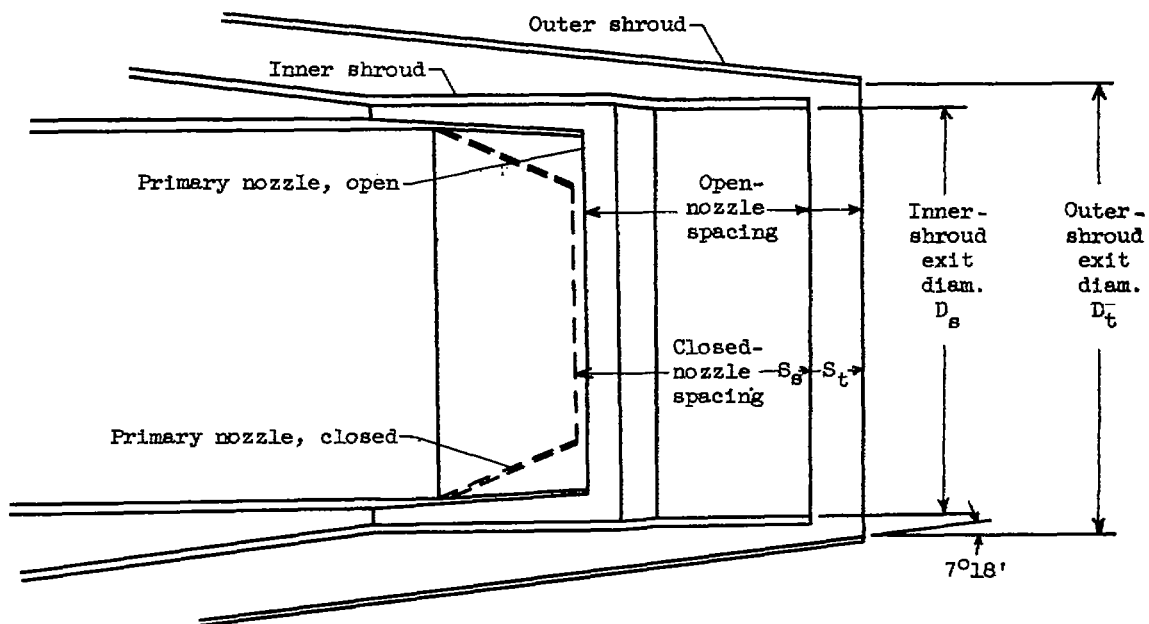
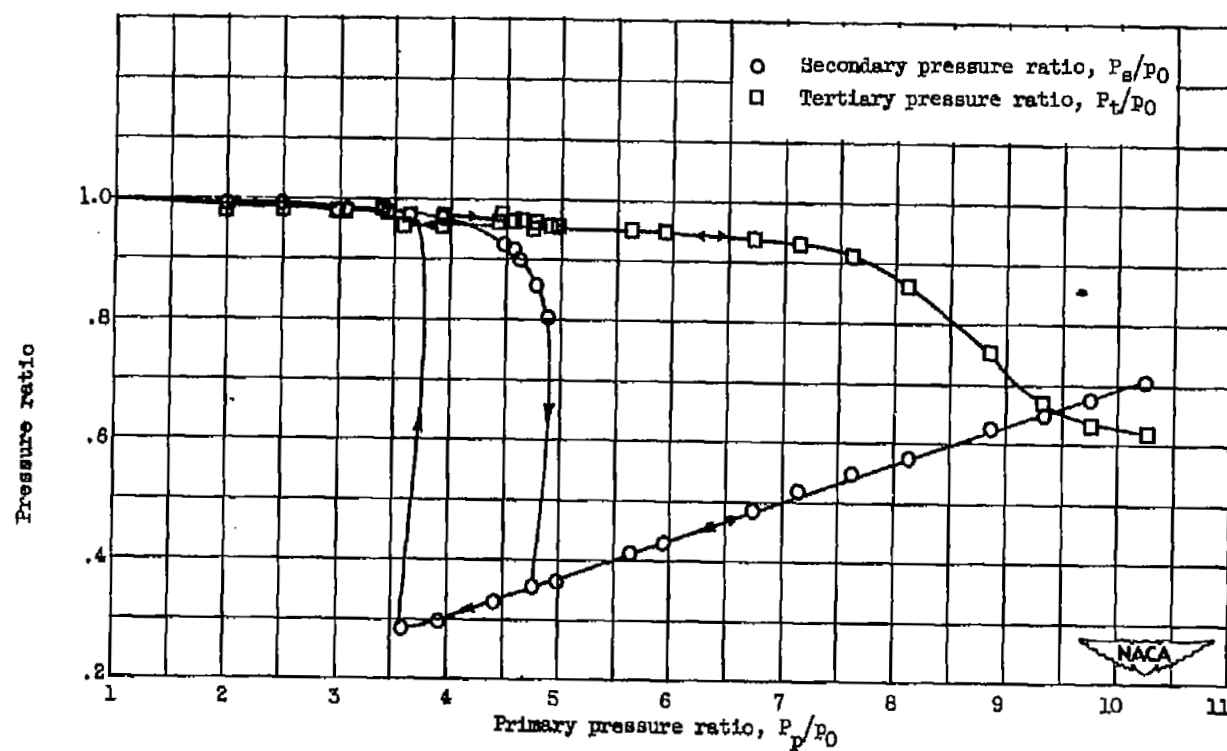


Figure 1. - Ejector-research facility.



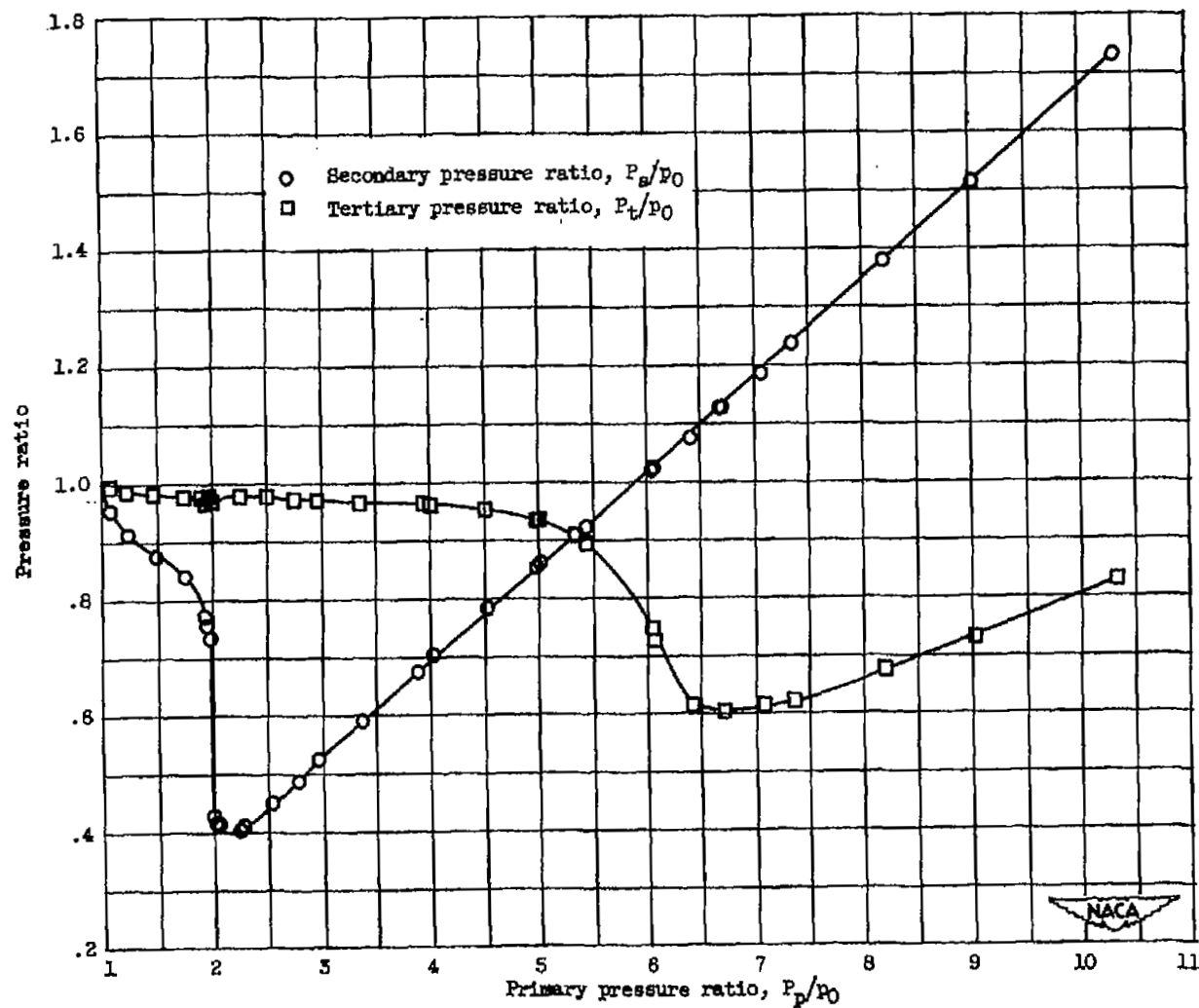
Nozzle position	D_p (in.)	D_s/D_p	S_s/D_p	D_t/D_p	S_t/D_p	D_t/D_s	S_t/D_s
Open	4.79	1.18	0.59	1.32	0.75	1.12	0.635
Closed	3.49	1.62	.86	1.80	1.07	1.12	.663

Figure 2. - Ejector notation and description of ejector models.



(a) Primary-nozzle position, closed.

Figure 3. - Double-shroud ejector performance. Zero cooling-air flow.



(b) Primary-nozzle position, open.

Figure 3. - Concluded. Double-shroud ejector performance. Zero cooling-air flow.

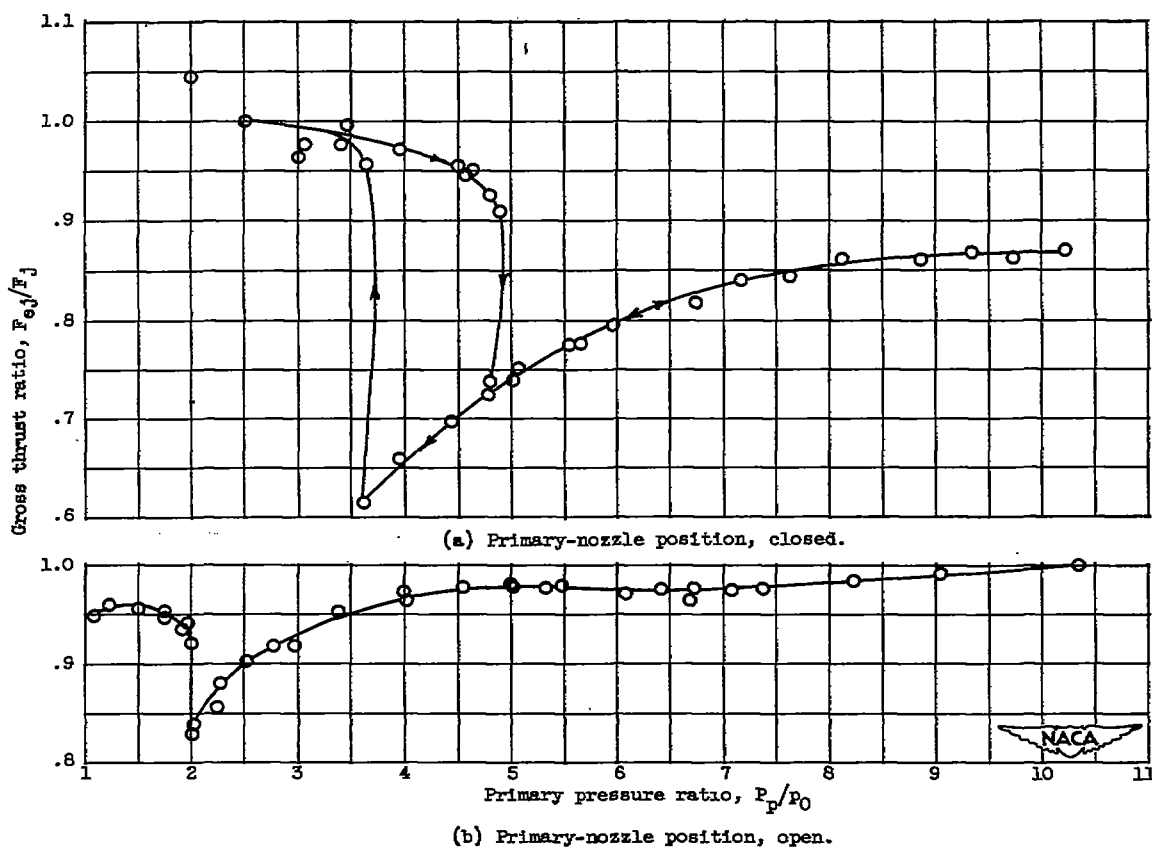
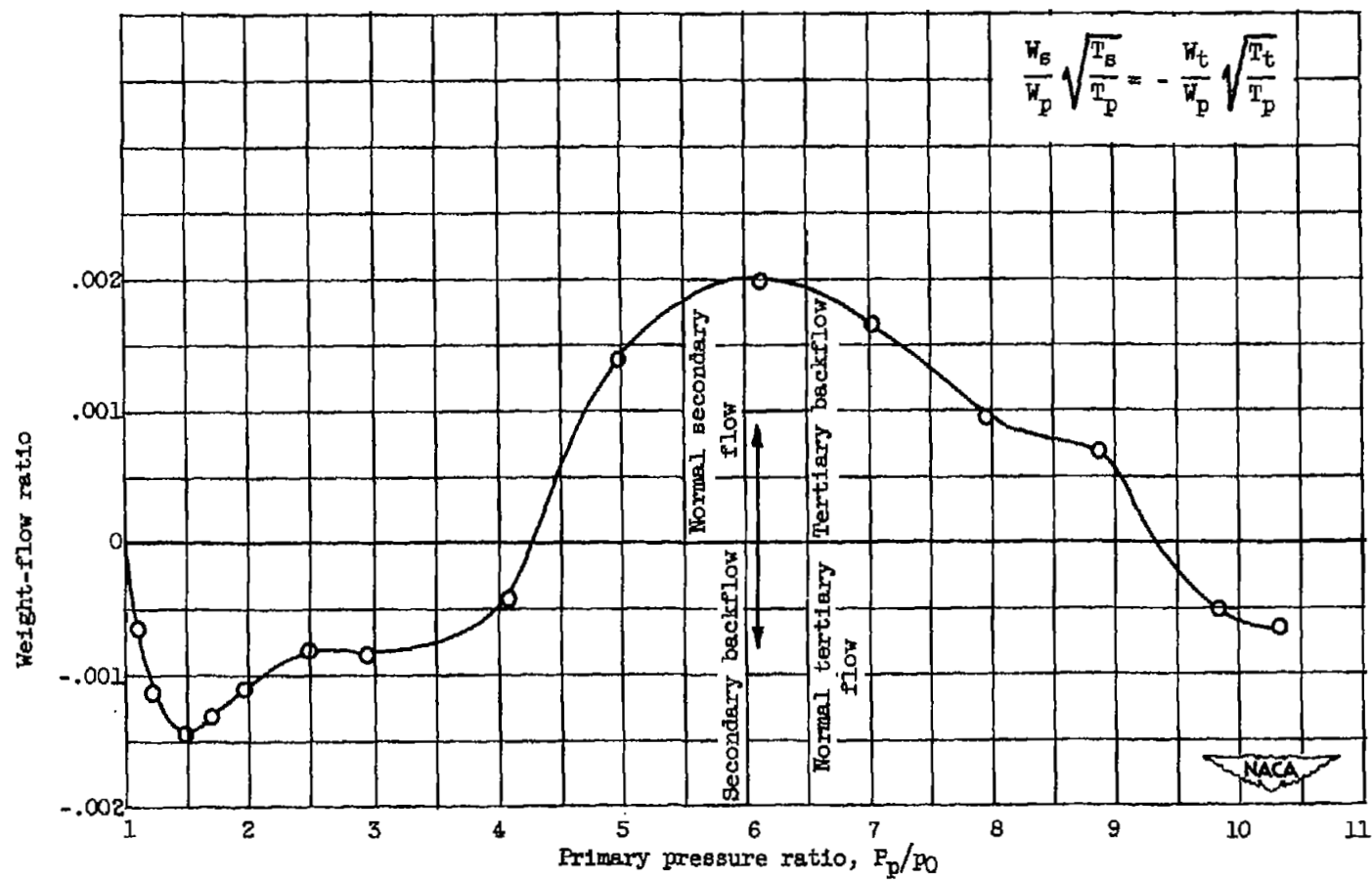
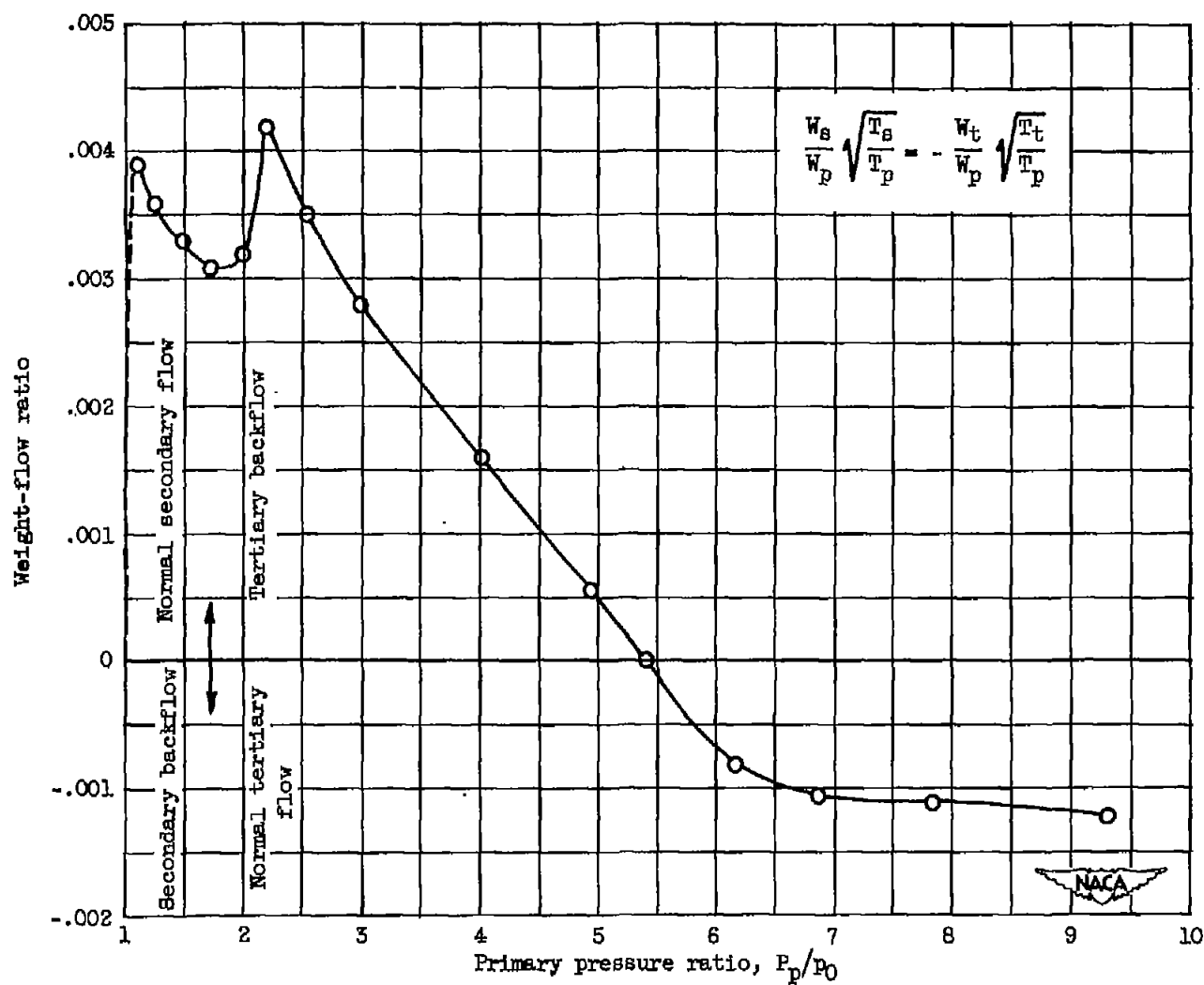


Figure 4. - Effect of primary pressure ratio on gross thrust ratio. Zero cooling-air flow.



(a) Primary-nozzle position, closed.

Figure 5. - Effect of primary pressure ratio on backflow.



(b) Primary-nozzle position, open.

Figure 5. - Concluded. Effect of primary pressure ratio on backflow.

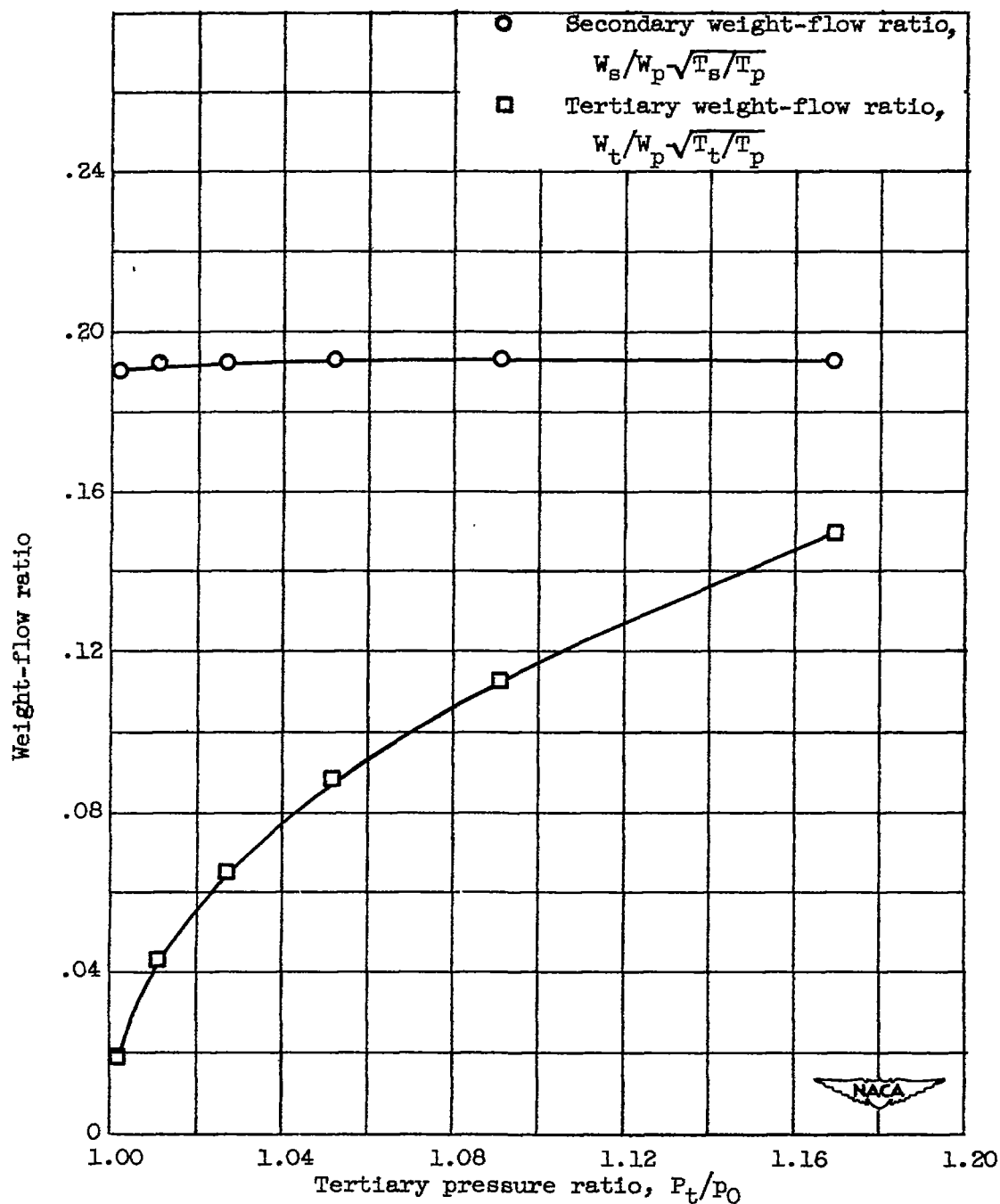


Figure 6. - Effect of tertiary pressure ratio on secondary and tertiary weight-flow ratios with primary nozzle in closed position. Primary pressure ratio, P_p/p_0 , 2.99; secondary pressure ratio, P_s/p_0 , 1.302.

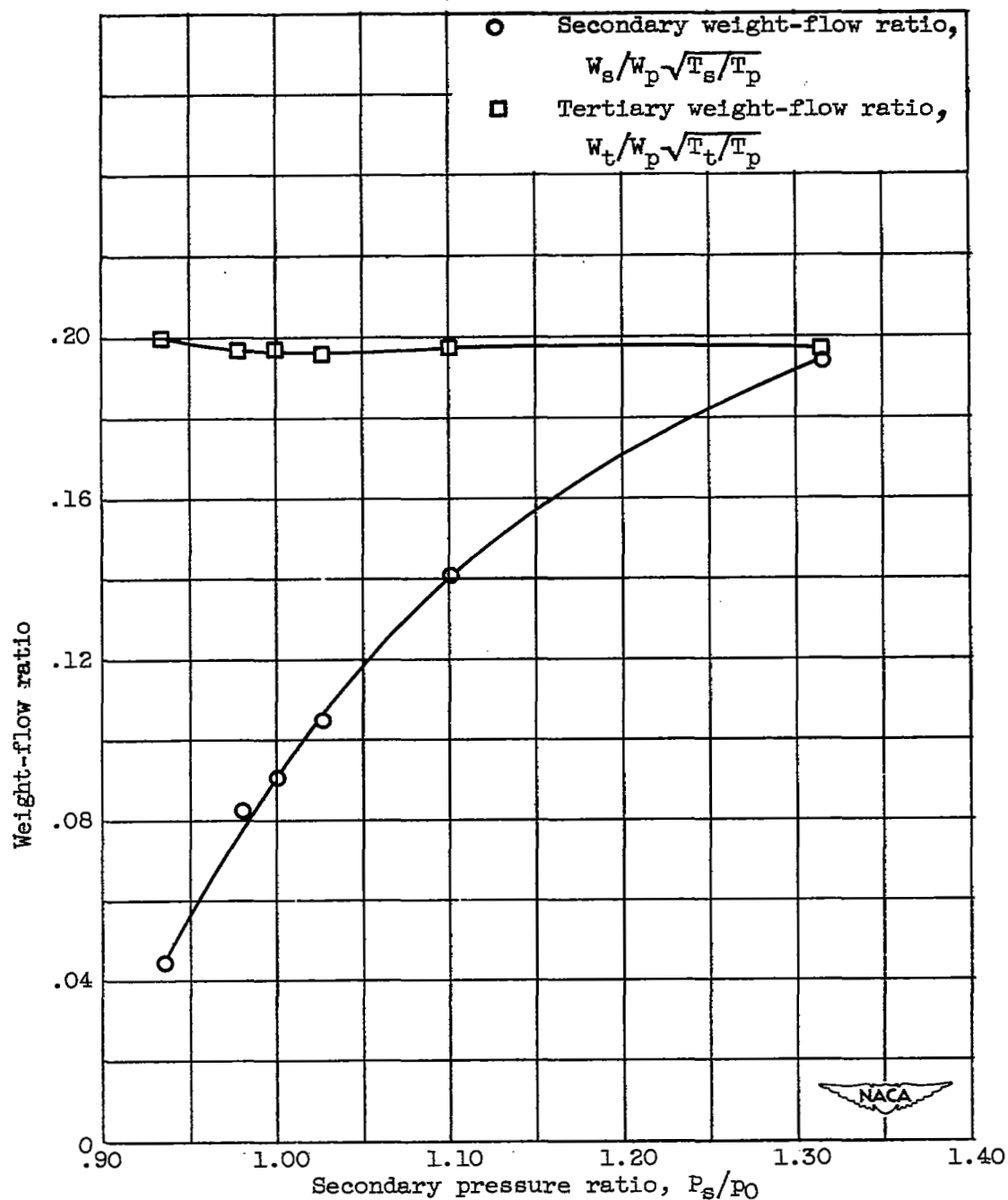


Figure 7. - Effect of secondary pressure ratio on secondary and tertiary weight-flow ratios with primary nozzle in closed position. Primary pressure ratio, P_p/p_0 , 2.99; tertiary pressure ratio, P_t/p_0 , 1.304.

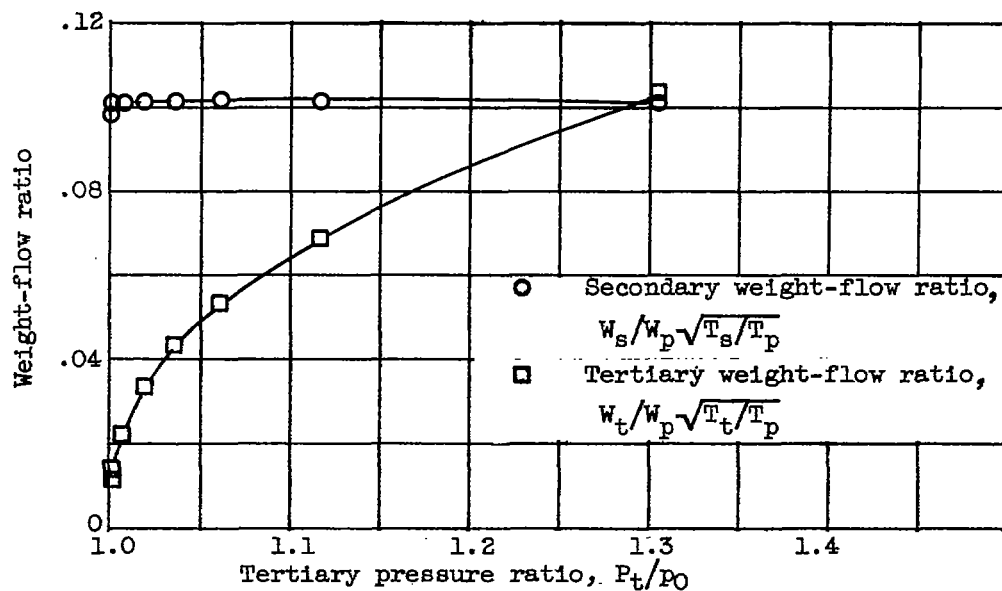


Figure 8. - Effect of tertiary pressure ratio on secondary and tertiary weight-flow ratios with primary nozzle in open position. Primary pressure ratio, P_p/P_0 , 3.0; secondary pressure ratio, P_s/P_0 , 1.304.

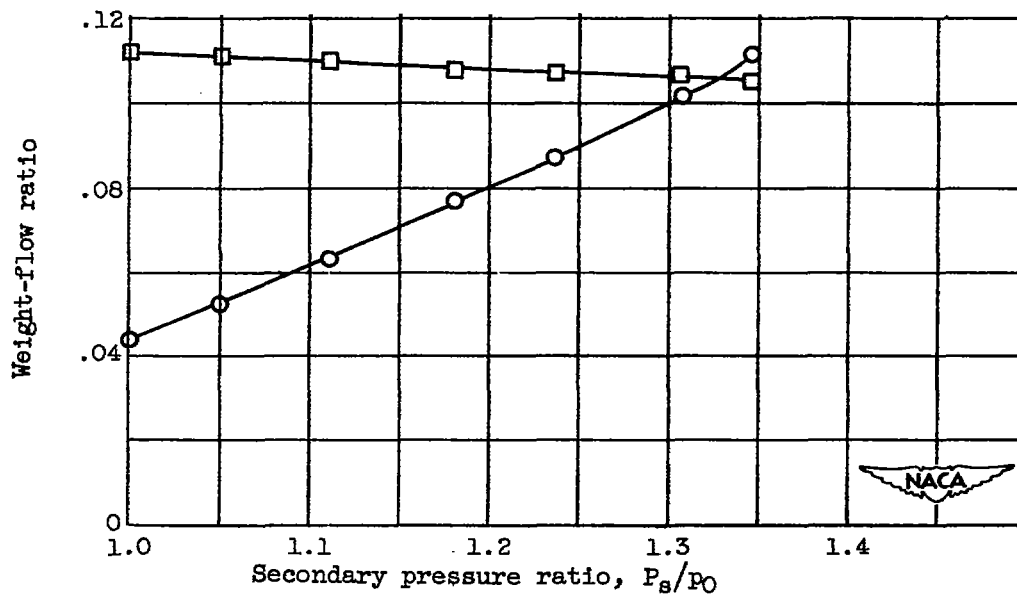
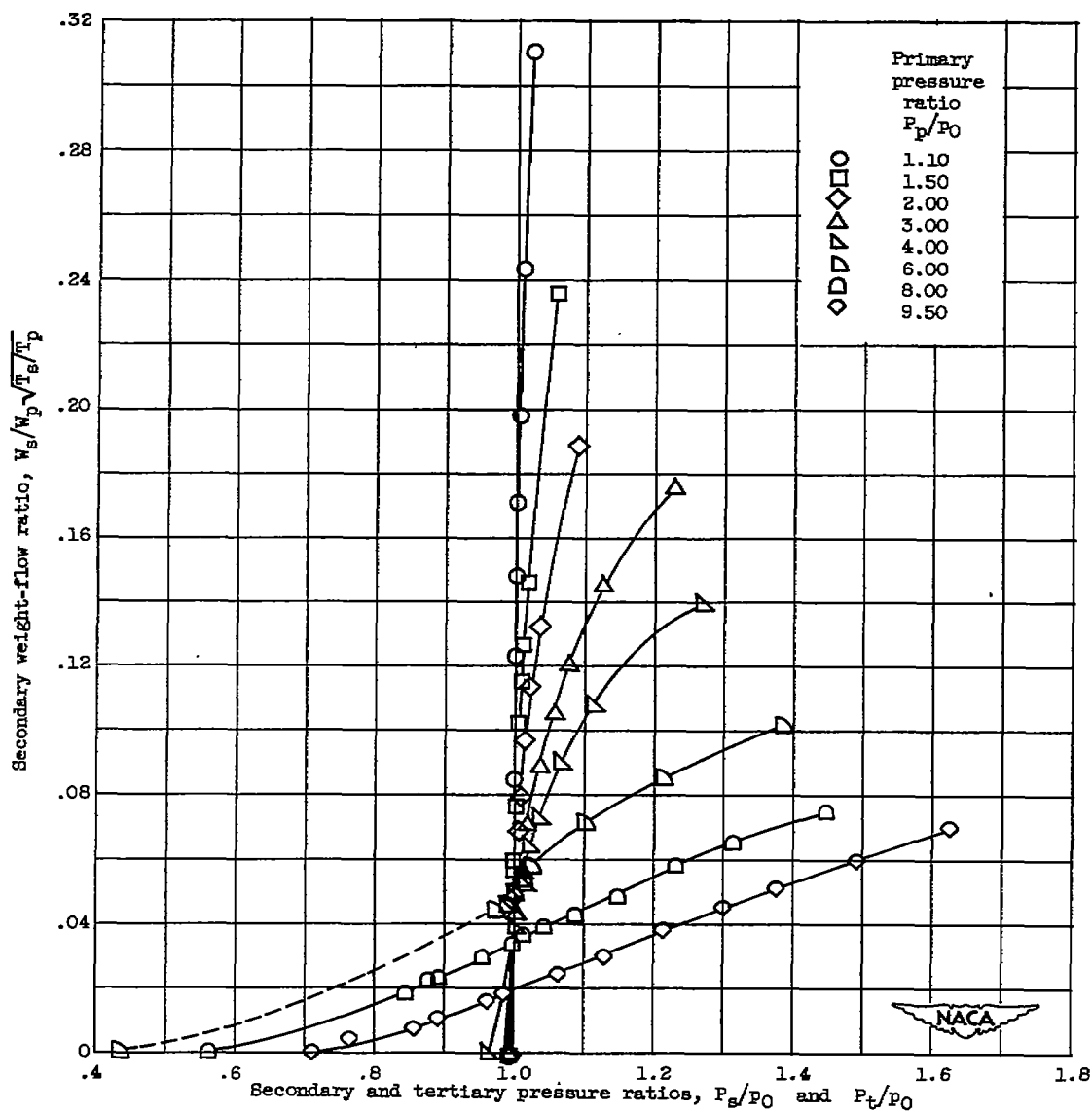
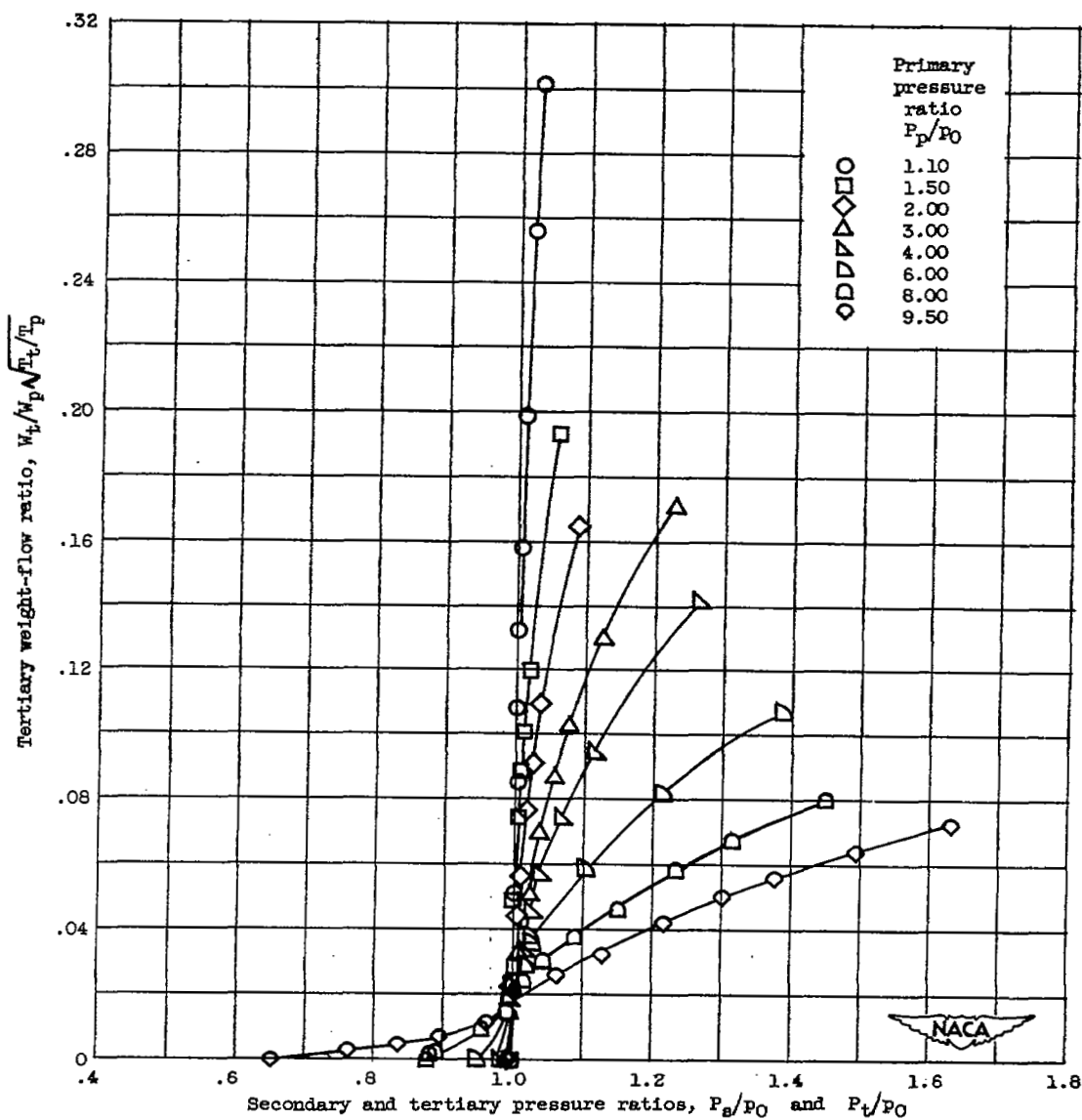


Figure 9. - Effect of secondary pressure ratio on secondary and tertiary weight-flow ratios with primary nozzle in open position. Primary pressure ratio, P_p/P_0 , 3.015; secondary pressure ratio, P_s/P_0 , 1.303.



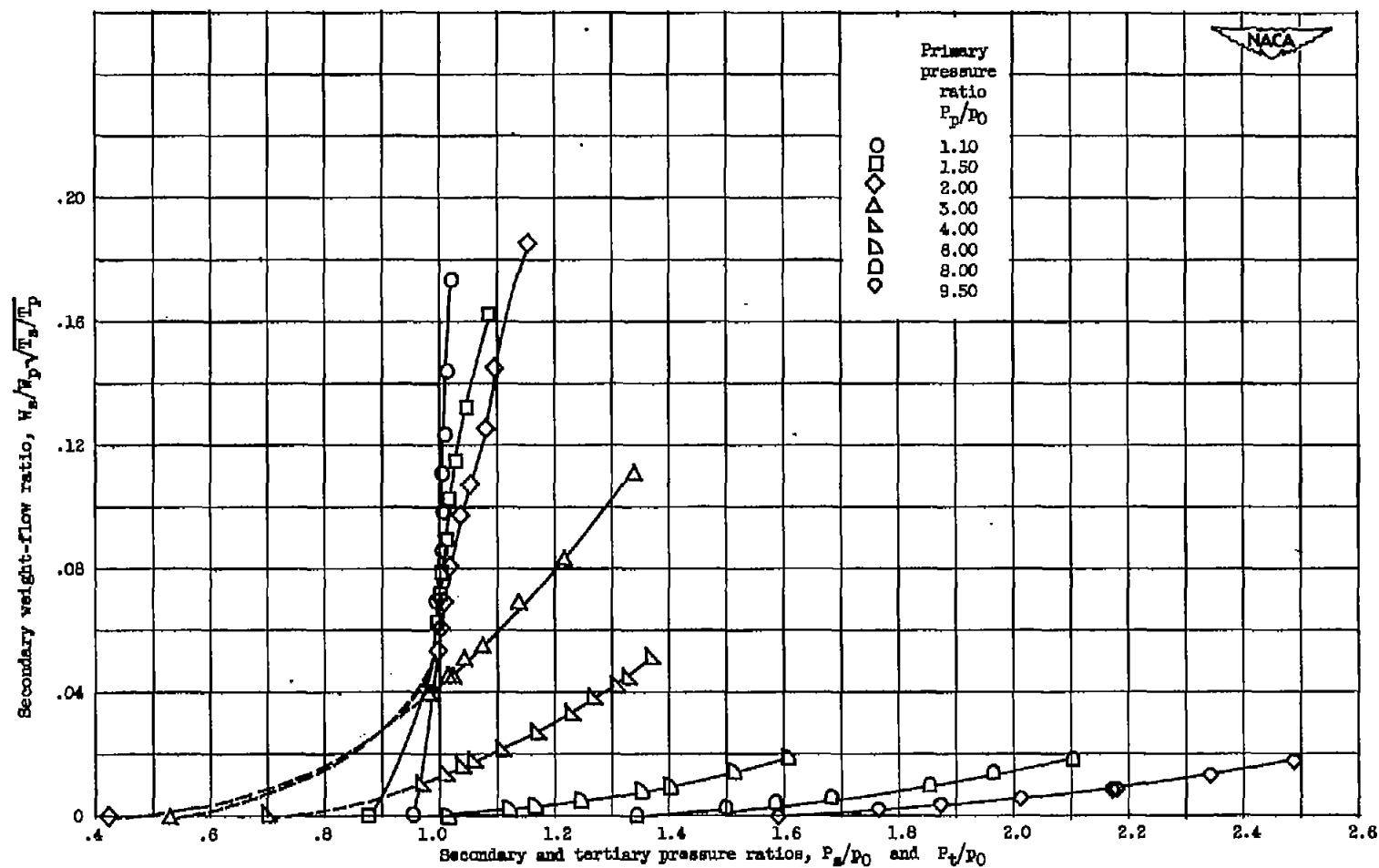
(a) Effect of secondary and tertiary pressure ratios on secondary weight-flow ratio.

Figure 10. - Double-shroud ejector pumping characteristics with primary nozzle in closed position.



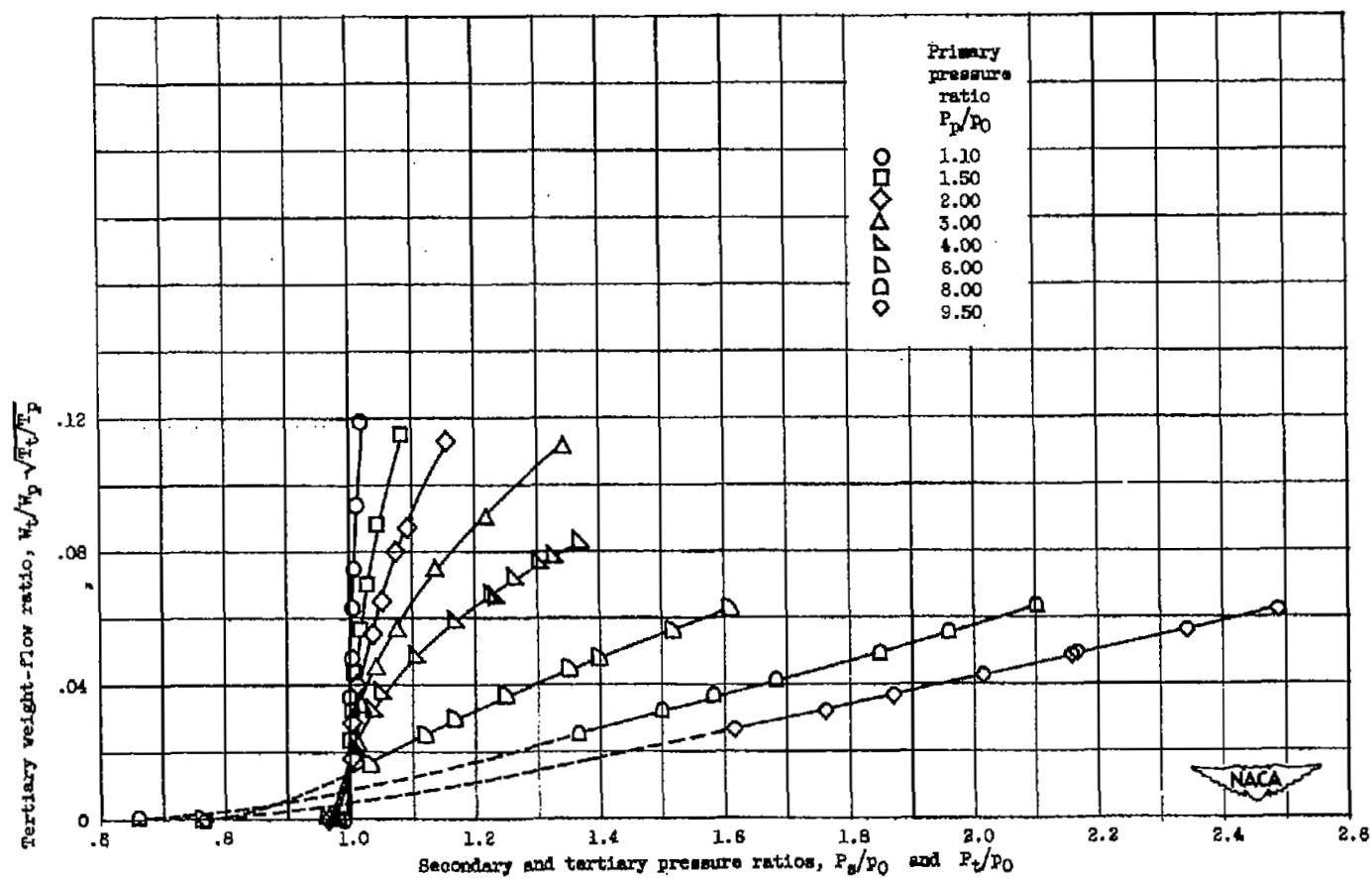
(b) Effect of secondary and tertiary pressure ratios on tertiary weight-flow ratio.

Figure 10. - Concluded. Double-shroud ejector pumping characteristics with primary nozzle in closed position.



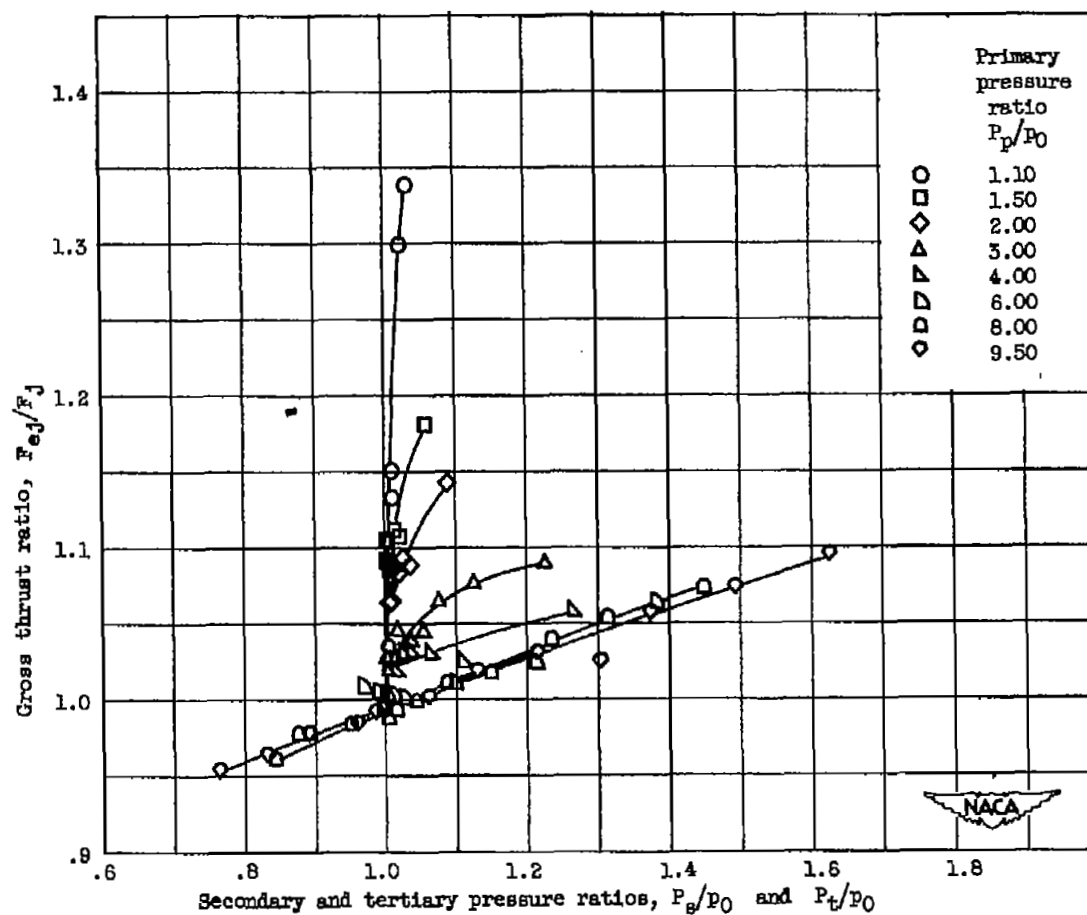
(a) Effect of secondary and tertiary pressure ratios on secondary weight-flow ratio.

Figure 11. - Ejector pumping characteristics with primary nozzle in open position.



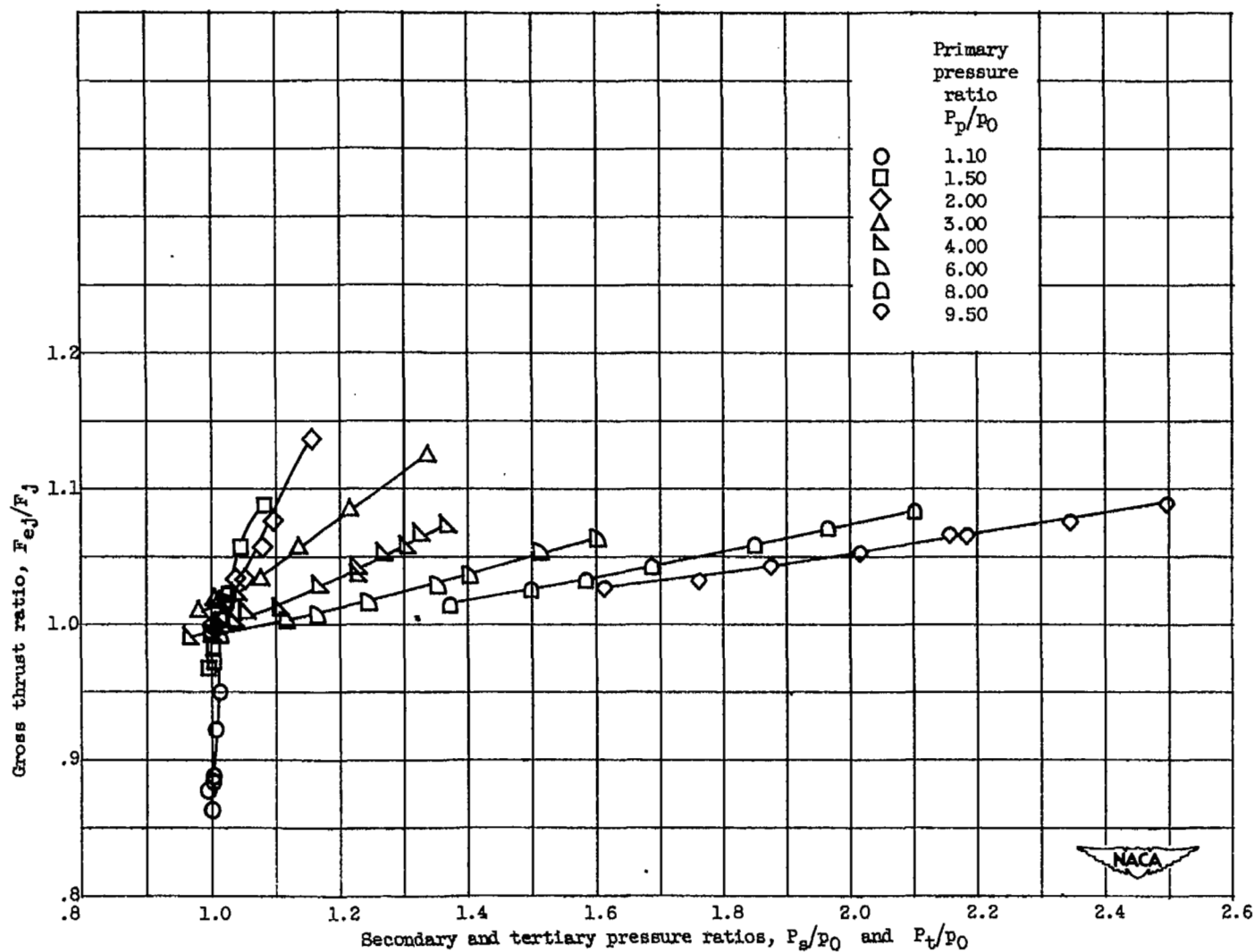
(b) Effect of secondary and tertiary pressure ratios on tertiary weight-flow ratio.

Figure 11. - Concluded. Ejector pumping characteristics with primary nozzle in open position.



(a) Primary-nozzle position, closed.

Figure 12. - Double-shroud ejector thrust characteristics.



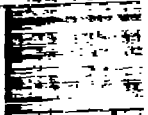
(b) Primary-nozzle position, open.

Figure 12. - Concluded. Double-shroud ejector thrust characteristics.

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